

TP 10810E



January 1991

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Welding Institute of Canada
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TP 10810E

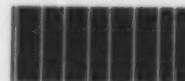
**EVALUATION OF NEW STEELS
FOR TANK CARS**

Prepared for
Transportation Development Centre
Policy and Coordination Group
Transport Canada

by
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Welding Institute of Canada Report RC 343/1/1990

CA1
DTR290-
91
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471793



41.D

January 1991

BDN 471792

The contents of this report reflect the views of the author and not necessarily the official views or opinions of the Transportation Development Centre of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la table des matières.

1. Transport Canada Publication No. TP 10810E		2. Project No. 7118		3. Recipient's Catalogue No.	
4. Title and Subtitle EVALUATION OF NEW STEELS FOR TANK CARS				5. Publication Date January 1991	
				6. Performing Organization Document No. PC 343/1/1990	
7. Author(s) Dr. S.R. Bala				8. Transport Canada File No. D1465-302-10	
9. Performing Organization Name and Address Welding Institute of Canada 391 Burnhamthorpe Road East Oakville, Ontario L6L 6C7				10. DSS File No. 15SD.T8200-8-8510-(651)	
				11. DSS or Transport Canada Contract No. T8200-8-8510/SD	
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 200 René Lévesque Blvd. West West Tower, Suite 601 Montreal, Quebec H2Z 1X4				13. Type of Publication and Period Covered Test Program 1989/91	
				14. Project Officer N.R. Gore	
15. Supplementary Notes (Funding programs, titles of related publications, etc.)					
16. Abstract The objective of this test program was to identify and test Canadian steels against the proposed AAR-TC-135 Grade B specification and supplementary weldment property requirements. Two candidate steels designated here as steel X and steel Y were evaluated. Both steels met the mechanical properties requirements in the as received condition. Steel X was found to be within the chemical specification requirements. Steel Y met the chemical specification with the exception of the inclusion of 0.39% Mo. Steel Y was found to have superior Charpy V-notch impact values before and after forming and stress relief treatments. Test butt welds were prepared in both candidate steels using the shielded metal arc welding (SMAW) and submerged arc welding (SAW) processes. The UTS and side bend test results of the weldments were favourable. The average and minimum CVN values were greater than 34 J and 27 J respectively at -46°C (a) for the as-welded SMAW welds in steel X and (b) for both the shielded metal arc and sub arc weldments in steel Y. It is concluded that the weldability and fracture toughness of weldments need to be investigated further.					
17. Key Words Tank car steel, hot form, stress relieve, tensile property, Charpy impact values, hardness, HAZ, weld metal, SAW, SMAW, TC-135.			18. Distribution Statement Limited number of copies available from the Transportation Development Centre.		
19. Security Classification (of this publication) Unclassified		20. Security Classification (of this page) Unclassified		21. Declassification (date) --	22. No. of Pages 40
				23. Price --	

1. N° de la publication de Transports Canada TP 10810E	2. N° de l'étude 7118	3. N° de catalogue du destinataire		
4. Titre et sous-titre EVALUATION OF NEW STEELS FOR TANK CARS		5. Date de la publication Janvier 1991		
		6. N° du document de l'organisme exécutant RC 343/1/1990		
7. Auteur(s) Dr. S.R. Bala		8. N° de dossier — Transports Canada D1465-302-10		
9. Nom et adresse de l'organisme exécutant Welding Institute of Canada 391 Burnhamthorpe Road East Oakville (Ontario) L6L 6C7		10. N° de dossier — ASC 15SD.T8200-8-8510-(651)		
		11. N° de contrat — ASC ou Transports Canada T8200-8-8510/SD		
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 200 ouest, boul. René-Lévesque Tour ouest, suite 601 Montréal (Québec) H2Z 1X4		13. Genre de publication et période visée Essai 1989/1991		
		14. Agent de projet N.R. Gore		
15. Remarques additionnelles (Programmes de financement, titres de publications connexes, etc.)				
16. Résumé L'objectif de la recherche était de reconnaître et de contrôler les propriétés de certains aciers élaborés au Canada par rapport à celles définies pour la nuance B de la spécification TC-135 de l'AAR et par rapport aux codes de soudage. La recherche s'est servie de deux aciers désignés ici acier X et acier Y. Ils ont tous les deux satisfait aux exigences relatives aux propriétés mécaniques à l'état de livraison. L'acier X a satisfait aux valeurs de composition chimique prescrites. L'acier Y également sauf pour l'addition voulue de 0,39 p. 100 de Mo. L'acier Y a dégagé des valeurs de résilience contrôlée sur éprouvettes Charpy-V supérieures aux valeurs prescrites, tant avant qu'après les opérations de formage et de détensionnement. Pour les essais de résilience, des éprouvettes, préparées à partir de ces deux aciers, ont été assemblées bout à bout par les procédés de soudage à électrode enrobée sous protection gazeuse (SMAW) et de soudage sous flux en poudre (SAW). Elles ont satisfait aux valeurs prescrites pour les essais de résistance à la rupture en traction et de flexion (sur chant). Les valeurs moyenne et minimale de résilience aux soudures, contrôlée à -46 °C, sont supérieures à 34 J et à 27 J, respectivement, aux états suivants : a) brut de soudage, électrode enrobée, (SMAW) cas de l'acier X seulement et b) brut de soudage, électrode enrobée sous protection gazeuse (SMAW) et sous flux en poudre (SAW), cas de l'acier Y seulement. Le rapport recommande de poursuivre davantage la recherche sur les caractéristiques de soudabilité et de résilience de ces aciers.				
17. Mots clés Aciers pour wagons-citernes, formage à chaud et froid, détensionnement, résistance à la traction, valeur de résilience Charpy, dureté, zone affectée thermiquement, métal fondu, soudage SAW et SMAW, acier nuance B TC-135.		18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.		
19. Classification de sécurité (de cette publication) Non classifiée	20. Classification de sécurité (de cette page) Non classifiée	21. Déclassification (date) --	22. Nombre de pages 40	23. Prix --

ACKNOWLEDGEMENTS

This project has been funded by Transport Canada and carried out at the Welding Institute of Canada. The steels for this program have been kindly supplied by both Mr. A. Riutta (Senior Metallurgist, Quality Engineering - Plate Products, Algoma Steel Corporation) and Mr. H.W. Ellison (Senior Product Metallurgist, Plate and Plate Skelp, Stelco Steel). Their help is gratefully acknowledged. Thanks are also due to Mr. S.D. Wong (Chief Engineer) and Mr. B. McClymont (Welding Technician, Rail Car Division), both of Procor Ltd. Mr. McClymont prepared the welds required for the project.



SUMMARY

Following a requirements evaluation by the Tank Car Committee of the American Association of Railroads (AAR) specifications were drafted for new tank car steels with the objective of improving impact toughness and weldability by reducing impurities and lowering carbon equivalent content compared to steels in current use.

Three grades of steels, A, B and C are included in the new specification AAR-TC-135. Grade A is similar to ASTM A808/A808M. Grade C is similar to the existing AAR-TC-128 Grade B steel. The third, Grade B has an intermediate chemical composition between Grades A and C. A test program has been carried out in the United States to evaluate American steels produced to these specifications.

The test program undertaken by the Welding Institute of Canada reported here was limited to Canadian steels produced to the Grade B AAR-TC-135 specifications.

The specifications provide only the properties required of the steels in the as received condition. Forming and stress relieving operations common in rail car fabrication could well degrade the properties of steel that meet the specifications on arrival at the fabrication plant. Therefore, it is not only important to verify whether the steels meet the basic specifications but also to determine degradation of properties that may occur as the result of forming and heat treating operations.

The first objective of this program was to identify Canadian steels that meet the basic requirements of steel produced to the Grade B AAR-TC-135 specifications.

The second objective was to check the end properties of these steels against the specification and supplementary weldments requirements after: hot forming in the range 566° to 900°C; cold forming up to 10% tensile strain; and, stress relieving and welding in various combinations to simulate different rail car fabrication cycles.

Two candidate Canadian steels designated here as steel X and steel Y made to the Grade B of the new specification by two Canadian sources, were evaluated in this program. Steel X was produced to meet the chemical properties of the specification. The steel met the mechanical properties of the specification in the as received condition. However, it yields below the specification for the as received condition after stress relief.

The Charpy V-notch (CVN) impact values were lower than those specified for the as received steel at -46°C when (a) stress relieved, (b) hot formed above 593°C plus stress relieved, (c) cold formed, and (d) cold formed plus stress relieved.

Steel Y was produced to the chemical specification with the exception that 0.39% Mo was deliberately added. This steel met the mechanical properties of 415 MPa yield strength, 550 to 690 MPa tensile strength and 34 J average/27 J minimum impact strength at -46°C in the

(a) as received, (b) stress relieved at 1150°C, (c) hot formed between 560°C and 900°C plus stress relieved, (d) cold formed at 5% and 10% tensile strain and (e) cold formed and stress relieved conditions.

Test butt welds were prepared in both candidate steels using the shielded metal arc welding (SMAW) and submerged arc welding (SAW) process. The ultimate tensile strength and side bend test results of the weldments were favourable for both steels. The average and minimum CVN values were greater than 34 J and 27 J, respectively, at -46°C (a) for the as welded SMA welds only in steel X and (b) for both the SMA and SA weldments in steel Y.

Even though the average CVN impact energy values at -46°C for the weld metal and HAZ greater than 34 J, average could be achieved in both the steels, the minimum values were lower than the 27 J minimum specified for the parent steel. However, the HAZ of steel Y seemed to yield CVN impact energy values greater than 34 J at -46°C, with occasional values lower than 34 J, in the as welded or the stress relieved condition.

Fracture toughness of the parent steel, HAZ, and weld metal needs to be determined for low temperature applications where defect tolerance assessments become important. The defects may be formed due to welding, fatigue, or other causes.

Welding procedures still need to be developed to obtain the HAZ and weld metal CVN toughness 34 J at -46°C minimum in the as welded and stress relieved conditions.

SOMMAIRE

Après que le comité des wagons-citernes de l'American Association of Railroads (AAR) eut effectué une analyse des besoins, il a fallu étudier des spécifications concernant les nouveaux aciers pour ces matériels et visant à en améliorer les caractéristiques de résilience et de soudabilité, par une réduction tant des impuretés que de la teneur carbone équivalente constatées dans les aciers courants.

La nouvelle spécification TC-135 de l'AAR définit trois nuances d'acier : A, B et C. La nuance A se compare à la nuance ASTM A808/A808M, la nuance C à la nuance actuelle TC-128 qualité B de l'AAR et la nuance B est à mi-chemin entre A et C. Des essais sont effectués aux Etats-Unis dans le but de connaître les propriétés des aciers élaborés dans ce pays selon ces spécifications.

Le volet canadien mené par l'Institut de soudage du Canada et dont il est rendu compte ici s'est limité aux aciers fabriqués au Canada selon la nuance B définie par la spécification TC-135 de l'AAR.

Dans ces spécifications, les propriétés définies sont celles à l'état de livraison. Les opérations de formage et de détensionnement, courantes lors de la fabrication des matériels roulants, se traduisent généralement par une détérioration de ces propriétés, dont il faut tenir compte. Il est donc impératif de contrôler les propriétés des aciers élaborés selon ces spécifications, non seulement à l'état de livraison, mais également après les opérations de formage et de traitement thermique.

La recherche a eu pour objectif principal d'identifier les aciers fabriqués au Canada qui ont les propriétés minimales définies pour la nuance B par la spécification TC-135 de l'ARR. L'autre objectif de la recherche était de contrôler les propriétés finales de ces aciers par rapport à celles définies par les spécifications et les codes de soudage, aux états particuliers suivants : après le formage à chaud à des températures entre 566 °C et 900 °C; après le formage à froid et à 10 p. 100 de la résistance à la traction du métal et après les opérations de détensionnement et de soudage selon les combinaisons utilisées pour simuler les différents cycles de fabrication.

La recherche s'est servie de deux aciers de fabrication canadienne, désignés ici acier X et acier Y, élaborés selon la nuance B de la nouvelle spécification. L'acier X, dont la composition chimique est conforme à la spécification, possède des propriétés mécaniques également conformes, mais à l'état de livraison seulement; après détensionnement, ces propriétés se situent en deçà de celles définies pour l'état de livraison.

Les essais de résilience contrôlée à -46°C sur éprouvettes Charpy-V ont donné des valeurs inférieures à celles définies pour l'état de livraison, aux états suivants : a) après détensionnement, b) après formage à chaud à des températures supérieures à 593°C plus détensionnement, c) après formage à froid et d) après formage à froid + détensionnement.

L'acier Y, dont la composition chimique est conforme à la spécification à l'exception de l'addition voulue de 0,39 p. 100 de Mo, a satisfait aux valeurs prescrites suivantes : limite d'élasticité 415 MPa, résistance à la rupture en traction entre 550 et 690 MPa et valeurs de résilience moyenne et minimale de 34 J et de 27 J, respectivement, contrôlée à -46°C aux états suivants : a) à la livraison, b) après détensionnement à 1150°C , c) après formage à chaud à des températures entre 560°C et 900°C + détensionnement, d) après formage à froid à 5 et 10 p. 100 de la résistance à la traction et e) après formage à froid plus détensionnement.

Pour les essais de résilience, des éprouvettes, préparées à partir de ces deux aciers, ont été assemblées bout à bout par les procédés de soudage à électrode enrobée sous protection gazeuse et de soudage sous flux en poudre. Elles ont satisfait aux valeurs prescrites pour les essais de résistance à la rupture en traction et de flexion (sur chant). Les valeurs moyenne et minimale de résilience des soudures, contrôlée à -46°C sont supérieures à 34 J et à 27 J, respectivement, aux états suivants : a) brut de soudage, électrode enrobée sous protection gazeuse, cas de l'acier X seulement et b) brut de soudage, électrode enrobée sous protection gazeuse et procédé sous flux en poudre, cas de l'acier Y seulement.

Bien que les valeurs moyennes de résilience contrôlée à -46°C du métal fondu et de la zone affectée thermiquement, (ZAT), aient été supérieures à la moyenne de 34 J dans le cas des deux aciers, les valeurs minimales, elles, sont inférieures à la valeur minimale de 27 J prescrite pour le métal de base. Cependant, dans le cas de l'acier Y à l'état brut de soudage et à celui après détensionnement, la ZAT a pu atteindre des valeurs de résilience contrôlée à -46°C supérieures à 34 J, avec des pointes tombant au-dessous de cette dernière.

La résilience aux basses températures du métal de base, de la ZAT aussi bien que celle du métal fondu doit être déterminée lorsque la tolérance aux défauts d'une application devient un facteur déterminant : défauts attribuables aux opérations de soudage, à la fatigue ou à tout autre cause.

Enfin, il faut mettre au point des procédures de soudage permettant à la ZAT et au métal fondu de conserver une valeur de résilience contrôlée à -46°C d'au moins 34 J tant dans l'état brut de soudage qu'après détensionnement.



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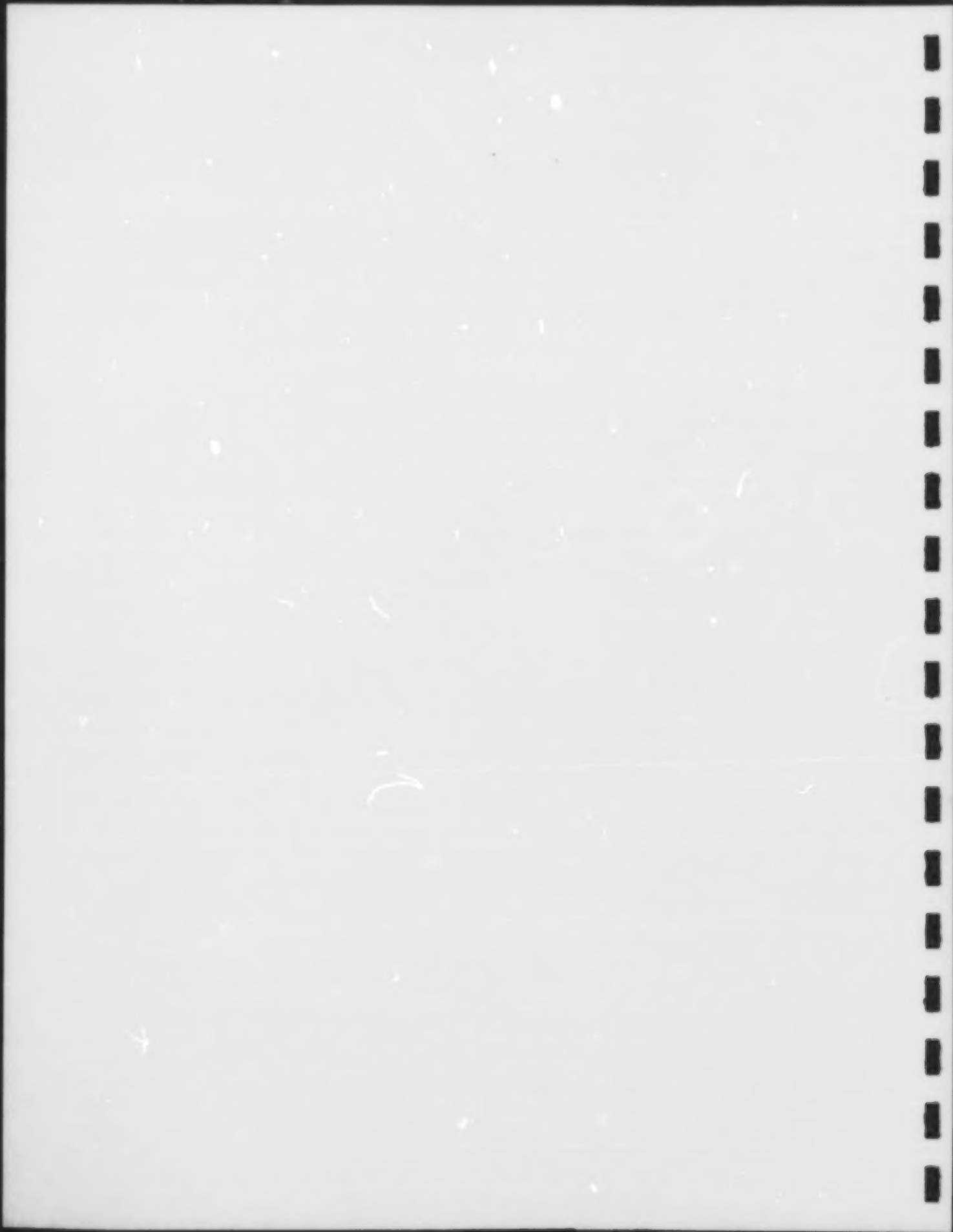
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EVALUATION OF NEW STEELS FOR TANK CARS

1.0 Introduction

1.1 Background

Following a review of new and existing steels for tank cars that was conducted by an ad hoc committee under the Association of American Railroads (AAR) Tank Car Committee, a follow-up evaluation of 13 promising steels was conducted by the Railroad Tank Car Safety Research and Test Project (1). Based on the evaluation program, a new specification for tank car steels was drafted (2). The draft standard initially identified three grades of ASTM A8XX steels. These grades were later called AAR TC-135 steels. Grades A and B are controlled-rolled steels having tensile strengths of 485 to 620 and 550 to 690 MPa (70 to 90 and 81 to 100 ksi) respectively. Grade C steel is normalized with a tensile strength of 550 to 690 MPa (81 to 100 ksi). The draft specification containing the chemical composition, tensile properties, and Charpy V-notch (CVN) impact energy requirements for the three grades is given in Appendix C.

These newer steel specifications are upgrades on the existing older AAR TC-128 Grade B steel whose composition and mechanical property requirements are also given in Appendix C. The AAR TC-128 Grade B steel is a higher strength steel similar to ASTM A 612/A 612M with higher levels of C (0.26% maximum) and carbon equivalents (CE) (0.66% maximum). This steel has a good weldability and a stringent toughness requirement of 20 J at -46° C. The older steels have high levels in C, S, and CEs. However, recent processing technologies involving microalloy additions, and control of S and thermomechanical means, have developed high-strength low-alloy (HSLA) steels with lower levels of C and S. These cleaner steels have good weldability due to lower levels of CEs, higher strength due to microalloying and thermomechanical processing, as well as good low temperature toughness due to S controls. ASTM A 808/A 808M is such an HSLA steel, possessing structural quality with improved toughness. The AAR Tank Car Committee's draft specification for TC-135 Grade A steel is similar to ASTM A 808/A 808M steel, but has a higher strength requirement than the latter. The specification for TC-135 Grade C is similar to the TC-128 Grade B, but with an improved notch toughness and a lower CE content. The specification for TC-135 Grade B includes thermomechanical processing with C and CE levels equal to the averages of those for Grades A and C and with strength levels matching those of Grade C. Refer to Appendix C.

Following the evaluation of steels that was used to draft AAR TC-135, a second test program was undertaken by the Railroad Tank Car Safety Research and Test Project. This project established the properties of steels ordered to the new specification that were available from American steel suppliers. It is desirable from the point of view of both the Canadian steel suppliers and rail car fabricators that Canadian steels that would meet the property requirements be included in the proposed new specification.

In view of these considerations, a test program similar to that conducted in the United States with American steels was essential to identify Canadian steels that would be able to meet the requirements of the new specification. This would provide R & D support to the regulatory authorities in the shipment of dangerous goods.

The new specification gives required properties for the as-received steel. However, subsequent forming and stress relieving operations common in any fabrication of rail cars could well degrade the properties of a steel that had arrived in the plant up to specification. It is important that designers have data on the end mechanical properties of steels used, so they can design rail cars without unnecessary over specifying.

The objectives of the present study were:

1. to identify steels from Canadian sources that meet the property requirements of the proposed new specification in the as-received condition; and
2. to check the end properties of these steels after forming, welding, and heat treatment operations commonly encountered in fabrication of rail cars.

Two commercial steels from Canadian sources, made to the requirements of the new AAR specification TC-135 Grade B, would be evaluated. Their mill specification mechanical and chemical properties were checked for conformity with the proposed specification. Various forming and stress relief operations were then performed on each candidate steel. The steels were to be subjected to hot forming, cold forming, stress relief, and welding operations in combinations to simulate different fabrication cycles. After each cycle, tensile and impact tests were performed and the results compared with the mechanical properties of the as-received steels. The weldment properties were compared to the expected tensile and CVN toughness properties for the TC-135 Grade B steel weldments put out by the AAR Tank Car Committee (Appendix C). The degree to which these commercial steels maintained their conformity to the proposed specification and/or expectations after fabrication was thereby established.

1.2 Scope of the Project

In this program, only the higher strength Grade B of the two controlled-rolled AAR TC-135 type steels was of interest. Hence, this project evaluated only steels made to AAR TC-135 Grade B spec. The test program included the following steps:

1. Procure steels made to AAR TC-135 Grade B specification from two major Canadian steel companies, Algoma Steel Corporation and Stelco Steel.
2. Determine the chemical compositions of these two candidate steels.
3. Determine the tensile properties and establish the CVN impact energy transition curves for both steels in the as-received and the stress relieved conditions.

4. Hot form the two as-received steels by heating and holding them at a temperature in the range of 560° to 900°C for one hour and then air cool them. Stress relieve the hot formed steels. Determine the room temperature tensile properties and the CVN impact energy at -46° C for the hot formed plus stress relieved steels.
5. Cold form the two steels by straining them in tension to 5% and 10% elongations. Determine the room temperature tensile properties and the CVN impact energy transition curves for these cold formed steels both in the as-formed as well as in the stress relieved conditions.
6. Evaluate the weldability of the two steels by examining both the weld metal and the heat affected zone (HAZ) properties in the as-welded and stress relieved conditions. The evaluation includes bend tests, reduced section tensile tests, weldment (HAZ and weld metal) Charpy impact, and hardness tests.

2.0 Experimental Procedures

2.1 Material

2.1.1 Steel

Two steels made to the AAR TC-135 Grade B steel draft specification were obtained from two major Canadian steel companies identified as sources A and B. These steels were identified as steel X (from source A) and steel Y (from source B). The thicknesses of steels X and Y were 14 mm and 19 mm respectively. The compositions and the mechanical properties taken from the mill reports are given in Appendix C.

2.2 Sectioning of the Steel Plates

Steels X and Y were sectioned as shown in Figures 1 and 2. Sections of steels X and Y were identified as X and Y, respectively and numbered from 1 to 29. The rolling direction was marked in each section.

2.3 Characterization of Steels

The chemical compositions of the steel plates from each source were determined for two locations of the plate - from sections X1 and X26 for steel X and from sections Y1 and Y26 for steel Y. The chemical compositions of the steels as analyzed by Triodem Technical Services Limited are given in Tables A1 and B1 (Appendices A and B).

Transverse tensile specimens with their tensile axes perpendicular to the rolling direction were prepared in duplicate for each steel in both the as-received (AR) and stress relieved (SR) conditions using sections X15 and Y15. The locations of tensile specimens are shown in Figure 3. Stress relieving of the steels was performed by

heating and holding the steels at 620° C for 1 hour, followed by furnace cooling. The dimensions of the tensile specimens are shown in Figure 4. The tensile tests were carried out as per ASTM A-370.

Longitudinal CVN specimens with their lengths parallel to the rolling direction and containing through-thickness notches (Figure 3) were prepared from the as-received sections X16 and Y16, as well as the stress relieved sections X17 and Y17. Lateral CVN specimens with their lengths transverse to the rolling direction were machined from both the as-received and stress relieved sections X18 and Y18. For each condition of the steel, CVN tests were carried out to obtain the full impact energy transition curve.

2.4 Hot Forming Tests

To examine the effect of soaking temperature followed by stress relief heat treatment on the mechanical properties of the steels, the following hot forming treatments were carried out.

Section Number	Soaking Temperature °C
X19, Y19	566
X20, Y20	593
X21, Y21	621
X22, Y22	649
X23, Y23	677
X24, Y24	760
X25, Y25	899

The hot forming treatments were carried out by bringing up the box furnace temperature to the soaking temperature and placing the plate sections inside the furnace. The control thermocouple was placed in between the sections. When the temperature in the sections reached the soaking temperature, which took about 20 minutes, the sections were held at the soaking temperature for 1 hour. After 1 hour soaking time the sections were removed from the furnace and air cooled. All the hot formed sections were then stress relieved at 620° C for 1 hour and furnace cooled.

Two transverse tensile specimens and five longitudinal CVN specimens were machined from each of the hot formed sections. The tensile tests were carried out at room temperature and the CVN tests were carried out at -46° C.

2.5 Cold Forming Tests

Tensile specimens of the sizes shown in Figure 5 were machined from the sections X6 to X13 and Y6 to Y13. The tensile specimens from sections X6 to X9 and Y6 to Y9 were strained in tension to 5% plastic deformation. The specimens from sections X10 to X13 and Y10 to Y13 were strained in tension to 10% plastic deformation. The cold formed specimens X8, X9, X12, X13, Y8, Y9, Y12, and Y13 were stress relieved at 620° C for 1 hour. For each cold formed specimen, with and without stress relief heat treatment, two transverse tensile specimens and 20 longitudinal CVN specimens were machined. For each cold formed and stress relieved condition, the tensile tests were carried out at room temperature and the CVN tests were carried out over a range of temperatures to obtain a full Charpy transition curve.

2.6 Tests Welds

2.6.1 Consumables

The shielded metal arc welding (SMAW) consumable, 3 to 4.8 mm diameter Atom Arc 8018-C1, conforming to AWS E55018-C1 specification, was used to perform all the low heat input butt welds. The submerged arc welding (SAW) consumable combination for the high heat input butt welds was 2.4 mm diameter Lincoln L56 wire and Lincoln 880M flux. SAW tests were run on the twin wire setup. All the test welds were prepared at Procor Limited.

2.6.2 Preparation of Butt Welds

The plate sections X2 to X5 and Y2 to Y5, 300 x 915 mm in size, were used to prepare butt welds. The rolling direction in each plate was parallel to the 300 mm side. Each plate was cut into halves parallel to the length (transverse to the rolling direction). Single-V grooves were machined along the length of the plates to give a 60 degree included angle for the butt joint with a 6 mm root face. The root gap was 3 mm for SMAW and 1.5 mm for SAW.

Butt welds were prepared in X2, X3, Y2, and Y3 plate sections using SMAW with E55018-C1 electrodes and a low heat input of about 1.4 kJ/mm. Similarly, butt welds were also prepared in X4, X5, Y4 and Y5 plate sections using twin wire SAW with Lincoln L56 wire-880M flux combination and a high heat input of 2.7 to 3.8 kJ/mm. All welds were prepared in the flat position by depositing side one first, then backgouging the reverse side to a U-groove by the air carbon arc method and finally welding side two. Welding data sheets 1 and 2 (Appendix A) and 3 and 4 (Appendix B) give the welding parameters and preheat temperatures.

The welds in plates X3, X5, Y3, and Y5 were stress relieved at 620° C for 1 hour. The following identifications were used for the low and high heat input welds:

Plate section	Identification	Condition
X2	XLA	as-welded (low HI)
X3	XLS	stress relieved (low HI)
X4	XHA	as-welded (high HI)
X5	XHS	stress relieved (high HI)
Y2	YLA	as-welded (low HI)
Y3	YLS	stress relieved (low HI)
Y4	YHA	as-welded (high HI)
Y5	YHS	stress relieved (high HI)

HI = heat input

2.6.3 Weldment Properties

Each weldment was sectioned as shown in Figure 6 to obtain specimen blanks for three weldment hardness profiles, three side bend tests, two reduced section tensile specimens, fifteen HAZ CVN specimens and ten weld metal CVN specimens. The lengths of the bend, tensile and CVN specimens were all parallel to the rolling direction. The notch in the weldmetal CVN specimen was through-thickness and machined at the geometric centre of the weld. The notch in the HAZ CVN specimen was also through-thickness and located so as to sample a higher percentage of the HAZ. The geometries of the tensile, bend, and CVN specimens, as well as their locations with respect to the weld, are shown in Figures 6 to 9. The tensile and bend tests were carried out at room temperature and the CVN impact tests were carried out at -46° C.

For determining the hardness profiles of the weldments, the weldment cross sections were ground, polished, and etched. Vickers microhardness, HV_{1000} , measurements were made on the cross section of the weldment traversing from base plate to the weld metal at a cusped region of the side two of the weld. The hardness readings were taken along a line parallel to the surface of the plate.

3.0 Results

3.1 Steel X

3.1.1 Chemical Composition

The chemical compositions of steel X are given in Tables A1 and A2. The composition of the steel is well within the proposed specification. Also, there is little variation in the compositions determined at two locations.

3.1.2 Tensile and Impact Properties of the As-Received Steel

The transverse tensile properties of the steel, obtained both in the as-received and the stress relieved conditions, are given in Table A3. The tensile properties of the as-received and the stress relieved steels met the tensile property requirement specified for the as-received material (ultimate tensile strength (UTS) = 550 to 690 MPa, yield strength (YS) = 415 MPa, and 20% elongation in 50 mm).

The longitudinal and transverse CVN impact energy data for both the as-received and the stress relieved conditions of the steel are given in Tables A4 to A7. The CVN impact energy transition curves plotted for the longitudinal and transverse specimens are shown in Figures 10 to 13. The longitudinal CVN impact energy transition curve of the as-received steel shows that the Charpy requirement of the specification at -46° C falls into the lower end of the transition region. Hence, the longitudinal CVN specimens for the as-received condition tested at -46° C given in Table A8 met the requirements of the specification. However, in the stress relieved condition a large scatter in CVN impact energy at -46° C was observed. The average energy value of 23 J obtained after stress relieving was lower than the average value of 34 J specified for the as-received steel.

3.1.3 Tensile and Impact Properties after Hot Forming

The transverse tensile properties of the hot formed steels determined after stress relieving are given in Tables A9 to A12. The YS and UTS values are plotted against the hot forming temperatures in Figure 14. The YS and UTS values decreased with the increase in the hot forming temperatures. The YS values were greater than or equal to the minimum YS values of 415 MPa specified for the as-received steel, when hot formed at temperatures up to 677° C and above this temperature the YS values were lower. However, the UTS values were lower than the minimum specified for the as-received steel (550 MPa) after hot forming at temperatures greater than or equal to 649° C and stress relieving.

The CVN impact energy values at -46° C determined after hot forming and stress relieving the steel are given in Tables A13 to A19. These Charpy energy values were also plotted against the hot forming temperatures in Figure 15. These CVN energy

values at -46°C closely matched the specified values for the as-received steel when hot formed and stress relieved up to 593°C and then deteriorated up to 677°C before improving over the specified values above 760°C .

3.1.4 Tensile and Impact Properties after Cold Forming

The tensile properties of the steel, in the as-formed and the stress relieved condition, after cold forming to 5% and 10% strain are given in Tables A20 and A21. The YS and UTS values are plotted against the cold formed strain in Figures 16 and 17. The tensile properties of the steels, except the elongation, met the minimum specified values for the as-received steel after cold forming up to 10% as well as after stress relieving following cold forming. However, the elongation after 10% cold forming was close to the specification. Stress relieving had little effect on the UTS of the cold formed steel when compared with the effect on the YS.

The CVN impact energy data for the cold formed steels is given in Tables A22 to A25. Figures 18 to 21 give CVN impact energy transition curves for the cold formed and cold formed plus stress relieved steels. The Charpy transition curves shifted to the right after cold forming so that the transition temperature increased with the increases in the amount of cold formed strain. The maximum shift in the transition temperature occurred when steels were cold formed to 5% strain. Above 5% strain the shift in the transition temperature was minimal because the CVN values are in the lower shelf region. Stress relieving did not seem to improve the transition temperature or the CVN energy. This can also be seen where the CVN energy at -46°C was plotted against the cold formed strain as shown in Figure 22. The average and minimum CVN values at -46°C for the cold formed steels in both the as-formed and stress relieved conditions were lower than those specified for the as-received material.

3.1.5 Properties of the Butt Welds

3.1.5.1 Hardness Traverses

The weld cross sections and the locations of the hardness traverses across the weldments are shown in Figures A1 to A16. The measured hardness values, HV_{1000} , are given in Tables A26 to A41. The maximum hardness values measured in the HAZ, weld metal and parent plate are given in the Table below. The maximum hardness values observed in the parent material in the as-welded and the stress relieved conditions are less than or equal to HV_{1000} 200. The maximum hardness in the weld metal and the HAZ for the SA welds were HV 219 and 225, respectively. On stress relieving, the maximum hardness observed in the weldments was HV 229 for the weld metal and 242 for the HAZ. Higher hardnesses were seen for the SMA weldments. In the as-welded condition the maximum hardnesses were HV 242 for the weld metal and 265 for the HAZ. In these weldments the maximum hardnesses after stress relieving were 229 for the weld metal and 261 for the HAZ. Hardnesses of the HAZ after stress relieving were higher than the hardness requirement of HV

234 maximum (HB 225 maximum) for the stress relieved SA weldments given in the Attachment 1 of Appendix C.

Weld ID	HV ₁₀₀₀		
	Weld Metal	HAZ	Parent Steel
XHA	219	225	202
XHS	229	242	195
XLA	242	265	210
XLS	229	261	203

3.1.5.2 Reduced Section Tensile Test Results

The reduced section tensile test results for both the SA and SMA welds in the as-welded and stress relieved conditions are given in Tables A42 to A49. In the as-welded and stress relieved conditions, the UTS values were greater than the minimum required UTS (550 MPa) for the weldment. Most of the tensile test fractures were outside the weld metal in the parent material.

3.1.5.3 Side Bend Test Results

The side bend test results for the SA and the SMA welds are shown in Table A50. Both welds passed the side bend test requirements.

3.1.5.4 CVN Impact Energy Values

The CVN impact energy values of the weld metal and the HAZ at -46° C for both the SA and SMA weldments in the as-welded and stress relieved conditions are given in Tables A51 to A58. A range of Charpy energy values at -46° C was seen. The range and the average Charpy energy values summarized for the weld metal and the HAZ are given in the Table below.

Procedure	Location	As-Welded CVN Values (J)		Stress Relieved CVN Values (J)	
		Range	Avg.	Range	Avg.
SAW	HAZ	8-143	59	13-117	41
	WM	8-13	10	18-65	40
SMAW	HAZ	18-102	44	22-69	42
	WM	47-90	65	25-42	33

WM = weld metal

The average Charpy energy values at -46° C for the weld metal and HAZ were higher than the 34 J average specified for the parent plate, or the minimum required for the weldment as per Attachment 1, except for the as-welded SA weld metal and stress relieved SMA weld metal. The minimum Charpy energy for the weld metal and HAZ were lower than the 27 J minimum specified for the parent plate except for the as-welded SMA weld metal.

3.2 Steel Y

3.2.1 Chemical Composition

This steel showed little variation in the compositions measured at two locations as shown in Tables B1 and B2. The chemical composition of the steel met the requirement of the specification, except for Mo. The steel contains 0.37 to 0.39% Mo which is higher than the specification requirement, but still meets the CE requirement of 0.47 maximum. Also, it is worth noting that the C, S, and P contents of this steel are low, i.e. 0.05, 0.004, and 0.007% respectively.

3.2.2 Tensile and Charpy Impact Properties of the As-Received Steel

The transverse tensile properties of the as-received and stress relieved steels are given in Table B3. The YS, UTS, and elongation values met the tensile property requirements specified for the as-received steel (i.e. 550 to 690 MPa UTS, 415 MPa YS, and 20% elongation in 50 mm).

The longitudinal and transverse CVN impact energy values of the as-received and stress relieved steels are given in Tables B4 to B7. The Charpy impact energy transition curves plotted for the longitudinal and transverse specimens are shown in Figures 23 to 26. The longitudinal and transverse specimens in the as-received and stress relieved conditions yielded Charpy energy values greater than the average 34 J at -46° C specified for the as-received steel.

3.2.3 Tensile and Impact Properties after Hot Forming

The transverse tensile properties of the steel after hot forming in the temperature range of 566° to 899° C followed by stress relieving are given in Tables B8 to B11. The YS and UTS values are plotted against hot forming temperature in Figure 27. There was little change in the UTS over a range of hot forming temperatures, except at 760° C. After a gradual increase in the YS up to 677° C, the YS dropped when hot forming was done at 760° C and then increased when hot formed at 899° C. A little drop in the UTS was also observed at 760° C. The UTS and YS values of the hot formed steel met the tensile requirements of the specification for the as-received material except for the YS when hot formed at 760° C. One of the two specimens tested from the hot formed steel at 760° C showed a YS value less than that specified, while the other one showed a higher value.

The CVN impact energy values at -46° C of the hot formed and stress relieved steels are given in Tables B12 to B18. These values are also plotted against the hot forming temperatures in Figure 28. The CVN values increased with the hot forming temperatures above 593° C. The minimum and average CVN values were greater than or equal to 198 J and 231 J respectively.

3.2.4 Tensile and Impact Properties after Cold Forming

The transverse tensile properties, in the as-formed and stress relieved conditions of the steels cold formed to 5% and 10% tensile strain are given in Tables B19 and B20. The tensile properties were well within the specification for the steel cold formed to 5% and/or stress relieved. The UTS values of the cold formed steel with 10% strain seem to exceed the range of UTS specified for the as-received steel. Also, elongation of the steel with 10% cold forming was lower than the specified value for the as-received steel. The YS and UTS values are plotted versus cold formed strain in Figures 29 and 30. The YS and UTS increased with an increase in cold forming tensile strain. There was little effect of stress relief heat treatment on the YS and UTS of the cold formed steel.

The CVN impact energy values of the cold formed steel in the as-formed and stress relieved conditions are given in Tables B21 to B24. The Charpy transition curves plotted for the cold formed and stress relieved steels are given in Figures 31 to 34. These plots show that the effect of cold forming above 5% strain seems to lower the upper shelf energy and have no effect on the transition region. Stress relieving seems to shift the transition region to the left i.e., transition temperature decreases. The CVN values at -46° C for the cold formed (up to 10%) and/or stress relieved steels greater than or equal to 114 J (minimum) and 211 J (average). The CVN values at -46° C plotted versus cold forming strain in Figure 35 showed large scatter in CVN values. Even so, there seems to be little change between 0 and 10% cold forming strain in the as-formed or stress relieved condition. At 5% cold strain the CVN values dropped but subsequent stress relieving improved them.

3.2.5 Properties of the Butt Welds

3.2.5.1 Hardness Traverses

The weld cross sections and the locations of the hardness traverses across the weldments are shown in Figures B1 to B15. The measured hardness values, HV₁₀₀₀, are given in Tables B25 to B39. The maximum hardness values measured in the weld metal, HAZ, and the parent metal are given in the Table below. The maximum hardness measured in the parent steel was less than or equal to 218 HV₁₀₀₀. The maximum hardness in the weld metal and HAZ for the SA weldments are 236 and 238, respectively. On stress relieving, the hardness values increased in the weld metal and HAZ to 253 and 296, respectively. Similar observations are also possible from SMA weldments. The maximum weld metal and HAZ hardnesses of 248 and 263 increased to 264 and 270, respectively on stress relieving. These weldment hardnesses were higher than the hardness requirement of HV 234 max given in Attachment 1 of Appendix C.

Weld ID	HV ₁₀₀₀		
	Weld Metal	HAZ	Parent Steel
YHA	236	238	211
YHS	253	296	205
YLA	248	263	217
YLS	264	270	218

3.2.5.2 Reduced Section Tensile Test Results

The tensile test results for both the SA and SMA welds in the as-welded and the stress relieved conditions are given in Tables B40 to B47. The UTS values of the weldments are well within the required value for the weldment and/or the range specified for the parent steel. All of these specimens fractured outside the weld metal.

3.2.5.3 Side Bend Test Results

Both the SA and SMA welds passed the side bend test requirements and the results are shown in Table B48.

3.2.5.4 Charpy Impact Energy Values

The CVN impact energy values at -46°C of the weld metal and HAZ, in the as-welded and stress relieved conditions, of the SA and SMA weldments are given in Tables B49 to B56. A range of CVN impact energy values at -46°C were seen. The range of CVN values and the average values are given in the Table below. In the as-welded conditions the Charpy toughnesses of weld metals at -46°C are greater than the 27 J minimum and 34 J average specified for the parent steel and/or required for the weldment. On stress relieving, these weld metals yielded less than the respective minimum and average Charpy toughness as specified for the parent steel and/or required for the weldment. On the other hand, in both as-welded and stress relieved conditions, the HAZ yielded higher average Charpy impact energy than the values specified for the parent plate. However, the minimum values are lower than the required minimum.

Procedure	Location	As-Welded		Stress Relieved	
		CVN Value (J)		CVN Value (J)	
		Range	Avg.	Range	Avg.
SAW	HAZ	15-325	202	67-325	257
	WM	28-54	45.2	12-24	17
SMAW	HAZ	23-325	247	21-325	199.5
	WM	47-78	56.2	22-40	33

WM = weld metal

4.0 Discussion

4.1 Steel X

The chemical composition of steel X was well within the specification and contained notably a low S level. The as-received steel met the tensile properties and CVN toughness requirements of the AAR TC-135 Grade B steel specification. However, it should be noted that the steel yielded a low range of CVN toughness. On stress relieving, the CVN impact energy deteriorated below the specified values for the as-received steel (refer to Table A8). When there were no mechanical property requirements specified for the end products, it was desirable to have the mechanical properties of the end products meet that of the steel specification.

The tensile properties of the steel hot formed in the temperature range 560° to 900°C and stress relieved showed that the YS and UTS was below the specified value for the as-received steel when hot forming at temperatures above 677° and 649°C ,

respectively. However, the CVN energy at -46°C of hot formed steel closely matched the specified values of 34 J average and 27 J minimum when hot formed and stress relieved up to 593°C and then deteriorated till 677°C before improving over the specified values of as-received steel above 760°C . This shows that the steel can be hot formed at temperatures up to 593°C and still probably meet the mechanical property requirements of the specification for the as-received steel.

The tensile properties of the steel that was cold formed to 5% and 10% strain closely met the tensile property requirement of the steel in the as-formed and the as-formed plus stress relieved conditions. However, cold forming to 5% and 10% strain deteriorated the CVN impact energy lower than the specified values for the as-received steel and stress relieving did not improve this CVN toughness.

The SA and the SMA weldments of this steel met the UTS requirement of the weldment or the steel specification and the side bend test requirement in the as-welded and the stress relieved conditions. However, the average Charpy energy values at -46°C for the weld metal and HAZ were higher than the 34 J average specified for the parent plate except for the as-welded SA and stress relieved SMA weld metals. The minimum Charpy energy for the weld metal and HAZ were lower than the 27 J minimum specified for the steel, except for the as-welded SMA weld metal. For both the SA and SMA weldments the average energy at -46°C obtained for the weld metal and the HAZ in the as-welded and/or stress relieved conditions were higher than the average of 34 J specified for the as-received steel or the minimum required by the weldment. However, the minimum CVN values obtained at -46°C were lower than the minimum specified for the steel and hence require welding procedure development to improve the minimum CVN energy values of the weld metal and HAZ.

4.2 Steel Y

On the other hand, steel Y except for Mo, had the chemical composition well within the specification requirement with notably low C, S, and P levels. However, this steel contained 0.37 to 0.39% Mo, which is well above the specification requirement. The tensile properties of the steel in the as-received and the stress relieved conditions met the specification requirements. The average and minimum CVN impact energy values at -46°C obtained for the as-received and stress relieved conditions of the steel were much greater than those specified for the as-received steel.

The tensile and CVN impact energy properties of the steel, except for UTS and elongation, when hot formed in the temperature range 566° to 899°C and stress relieved, met the mechanical property requirements of the as-received steel. However, the UTS of the steel after 10% cold forming exceeded the specified range of the as-received steel and stress relieving did not affect the UTS of the cold formed steels. The elongation value after cold forming to 10% strain was lower than that specified for the as-received steel.

Even though steel Y showed excellent tensile and CVN toughness properties after hot and cold forming, the weldment properties of this steel were not so good. The SA and SMA weld metal side bend test results were acceptable and the UTS values of the weldments were well within weldment requirements or the range specified for the parent steel. However, the CVN toughness values at -46°C were not so attractive. In the as-welded condition the weld metal yielded average and minimum CVN impact energy values greater than those specified for the parent steel. On stress relieving, the weld metal yielded CVN toughnesses lower than those specified for the parent steel. In the as-welded and the stress relieved conditions of the HAZ, the average CVN toughnesses were generally well above the average specified for the parent steel or the minimum required by the weldment, while the minimum values were lower than those specified for the parent steel. Thus, there is still ample scope for the development of welding procedures to improve the weld metal and HAZ toughness so that the CVN toughness requirements of the as-received parent steel can be met by the weldments.

4.3 Comparison of Steels X and Y

Steels X and Y are both much cleaner steels with C and CE much lower than the AAR TC-128 Grade B steel specification. TC-128 steel can have C up to 0.25% and CE $\sim 0.66\%$. Specification for AAR TC-135 Grade B steel requires higher toughness (34 J average and 27 J minimum at -46°C) than the AAR TC-128 Grade B steel specification (20 J average and 14 J minimum at -46°C). Steels X and Y, in the as-received condition, met the toughness requirement of the AAR TC-135 Grade B specification.

Steel X which met the chemical requirement of the AAR TC-135 Grade B steel specification, yielded only the low range of the mechanical property requirements, especially the CVN toughness at -46°C , in the as-received condition. On stress relieving, the CVN toughness at -46°C did not meet the requirement of 34 J average and 27 J minimum specified for the as-received steel. Also, there was difficulty in obtaining CVN toughness of 34 J average and 27 J minimum at -46°C , in the end products after cold forming, hot forming, and weld metal fabrication. Stress relieving the end products did not improve the CVN toughness to the specification requirement of the as-received steel.

On the other hand, steel Y contained Mo in an amount higher than specified. As a result of their past experience, the steel company intentionally added more Mo to this steel to achieve the CVN impact energy requirement of the as-received steel even after stress relieving at temperatures up to 1200°C . This steel showed greater potential in representing the AAR TC-135 Grade B steel specification by meeting the tensile and impact properties of the as-received steel specification even after stress relieving, cold forming, hot forming, welding, and stress relieving, after forming and welding operations.

All of the American steels, evaluated both in the as-received and the stress relieved condition by the AAR, met the tensile and impact property requirements of the respective Grades of AAR TC-135 specification (refer to Appendix C). However, many of the SA weld metals in these steels, after stress relieving, showed poor CVN toughness at -46°C . Even though there are not many HAZ CVN toughness values reported, those that are reported show acceptable values, meeting the AAR TC-135 specification. Weld metals in Steels X and Y also showed lower impact toughness ($< 34\text{ J at } -46^{\circ}\text{C}$) after stress relieving even though the HAZ toughness values were marginally acceptable. Further studies are required to characterize the weldability, weld metal toughness, and HAZ toughness of Steels X and Y.

5.0 Summary

1. Steels X and Y made to AAR TC-135 Grade B steel specification were supplied by two of the major Canadian steel companies.
2. The chemical compositions of steel X met the AAR TC-135 Grade B steel specification. However, steel Y did not meet the specification requirement only because it contained above-specification Mo ($\sim 0.37\%$). The rest of the elements in steel Y were well within the specification requirement.
3. The tensile properties of both the steels were well within the specification and still met the specification requirement after stress relieving.
4. Both steels, in the as-received condition, met the specified CVN impact requirements at -46°C . Steel X yielded a low range of CVN energy comparable to the specified values for the steel. On the other hand, steel Y containing Mo, low C, low S, and low P yielded much higher CVN impact energy values. On stress relieving, the CVN values at -46°C for steel X were lower than those specified for the as-received steel. Steel Y yielded much higher CVN impact energy than specified even after stress relieving.
5. The hot forming was carried out at specific temperatures in the range 566° to 900°C followed by stress relieving. The tensile properties and the CVN impact energy values measured at -46°C on the hot formed and stress relieved steels met the specification requirement of the as-received steel when steel X was hot formed up to 593°C and stress relieved. However, in the case of steel Y, after hot forming and stress relieving, the tensile properties and CVN toughness met the specification requirements of the as-received steel.
6. The tensile and CVN impact energy properties were determined after cold forming the steel to 5% and 10% tens

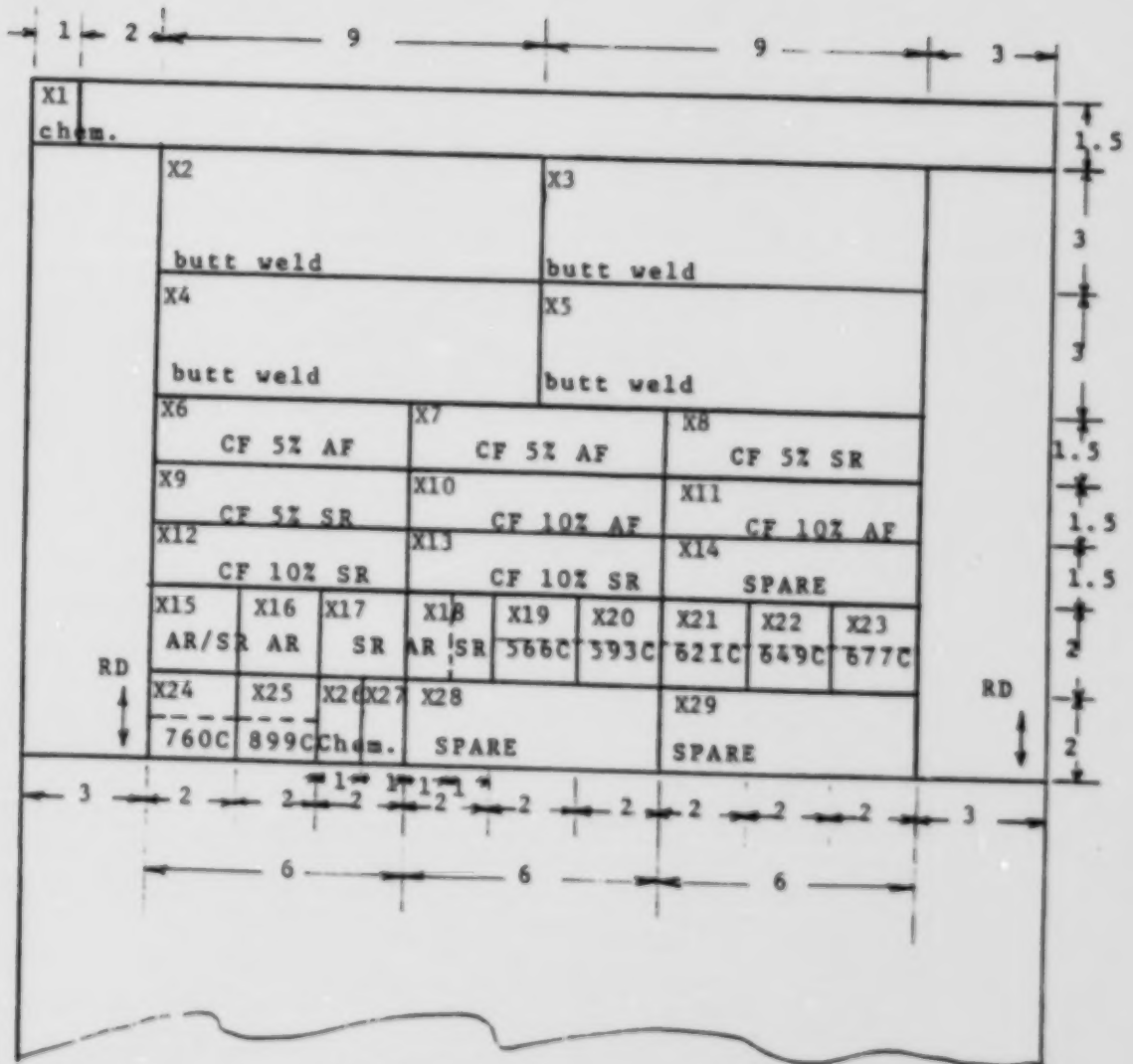
7. The butt welds were prepared in both the steels using SMA and SA welding processes. The mechanical tests such as hardness tests, reduced section tensile tests, side bend tests, and CVN impact tests were carried out for the weldments in the as-welded and stress relieved conditions.
8. The maximum hardnesses, HV_{1000} , seen in the weld metal and HAZ in the as-welded and stress relieved weldments were 242 and 265 for steel X and 264 and 296 for the steel Y. These hardnesses were higher than the HV 234 (HB 225) maximum required by the weldments.
9. The side bend test results of the weldments were acceptable and the UTSs of the weldments were well within the specified range for the parent steel or the values required by the weldments.
10. The average and minimum CVN values greater than 34 J and 27 J, respectively at -46°C were obtained in the as-welded SMA welds of steel X.
11. The average and minimum CVN values greater than 34 J and 27 J, respectively at -46°C were obtained in both the as-welded SMA and SA weldments of steel Y.
12. Even though the average CVN impact energy values at -46°C for the weld metal and HAZ greater than 34 J, average could be achieved in both the steels, the minimum values were lower than the 27 J minimum specified for the parent steel. However, the HAZ of steel Y seemed to yield CVN impact energy values greater than 34 J at -46°C , with occasional values lower than 34 J, in the as-welded or the stress relieved condition.

6.0 Recommendations

1. The weldability of the steels needs to be established.
2. Welding procedures still need to be developed to obtain the HAZ and weld metal CVN toughness 34 J at -46°C minimum in the as-welded and stress relieved conditions.
3. Fracture toughness of the parent steel, HAZ, and weld metal needs to be determined for low temperature applications where defect tolerance assessments become important. The defects may be formed due to welding, fatigue, or other causes.

7.0 References

1. Report RA-03-7-53 (AAR R-643), "Evaluation of New Steels for Tank Cars", April 29, 1987.
2. ASTM A8XX, "Pressure Vessel Plates, High Strength Low Alloy", Draft - January 18, 1988.
3. Railroad Tank Car Safety Research and Test Project, "Steel Program Test Plan", Draft 5/27/88, May 31, 1988.
4. ANSI/AWS D 1.1 - 90, An American National Standard, "Structural Welding Code - Steel", AWS, 1990.



All dimensions are in 100mm.

Figure 1. Sectioning of steel X plate and specimen identification.

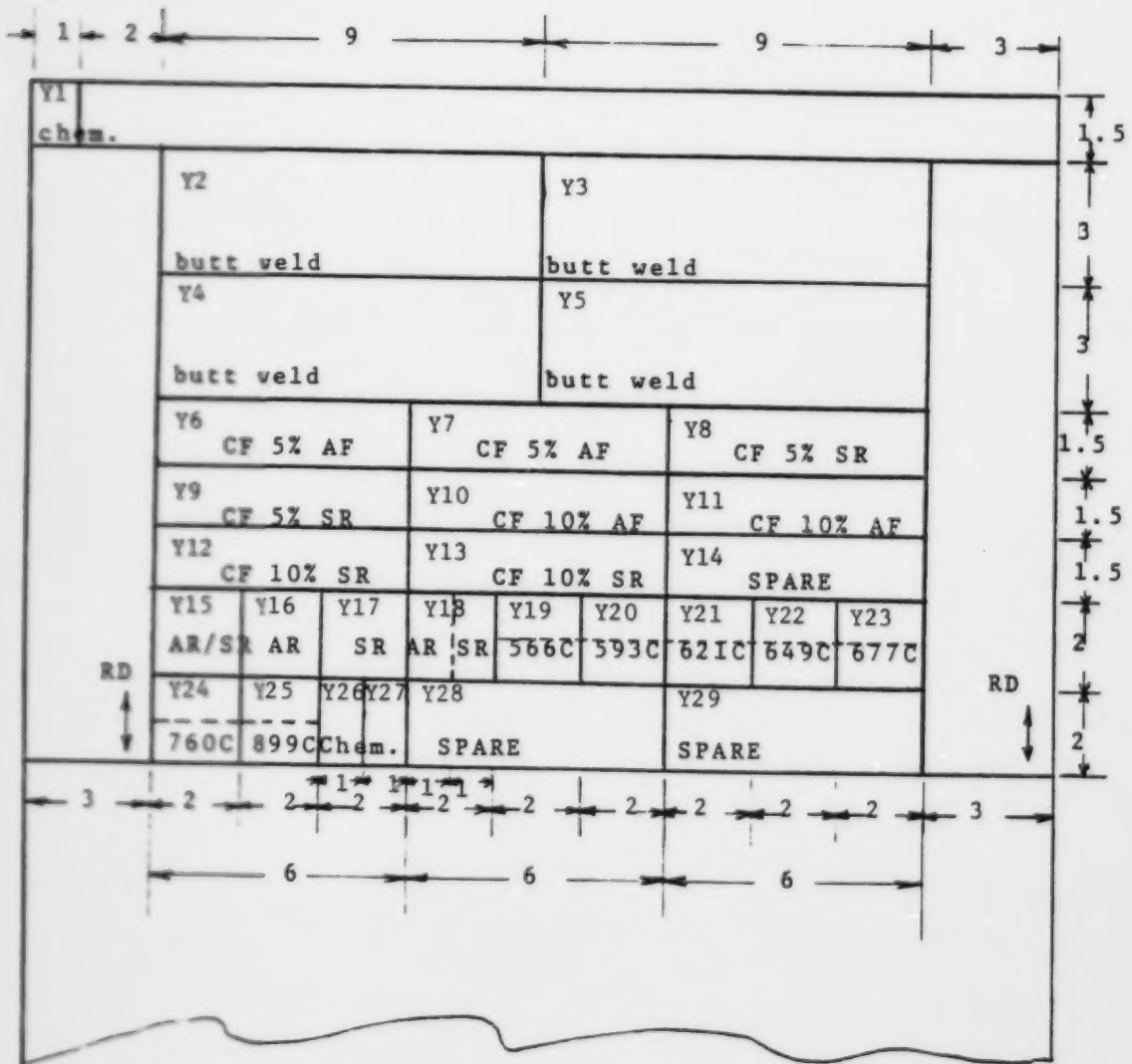
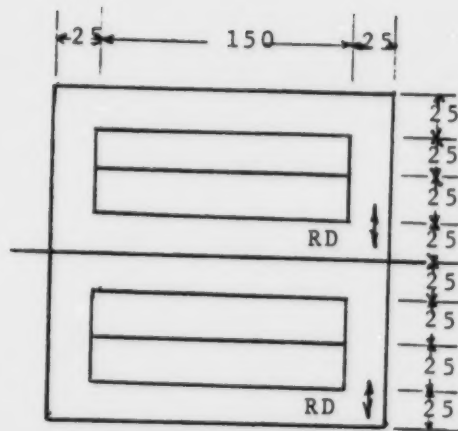
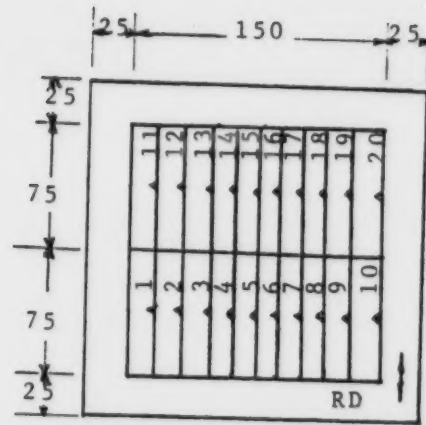


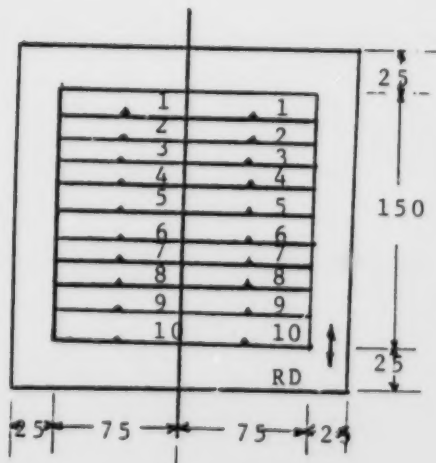
Figure 2. Sectioning of steel Y plate and specimen identification.



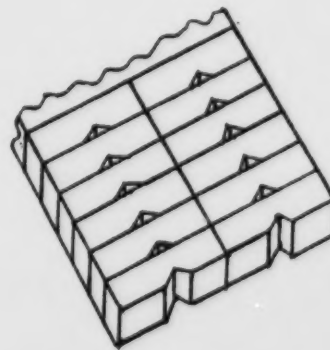
(a) Transverse Tensile Specimen Blanks



(b) Longitudinal CVN Specimen Blanks



(c) Transverse CVN Specimen Blanks



All dimensions are in mm.
Specimens prepared from T/2
locations.

- Rolling direction.

Figure 3. Locations of tensile and Charpy blanks.

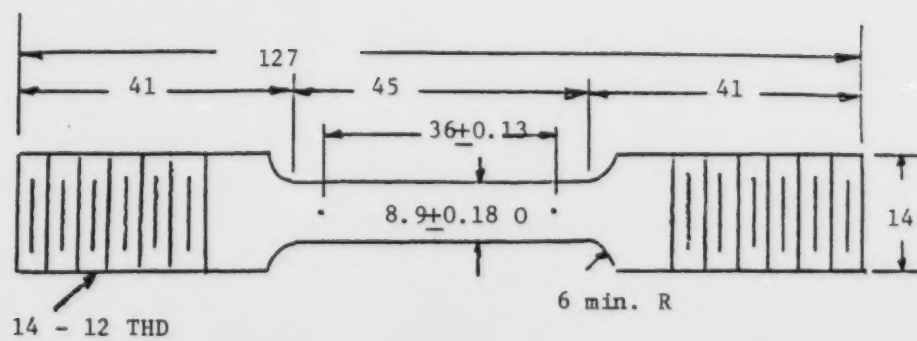


Figure 4. Dimensions (in mm) of the tensile specimens.

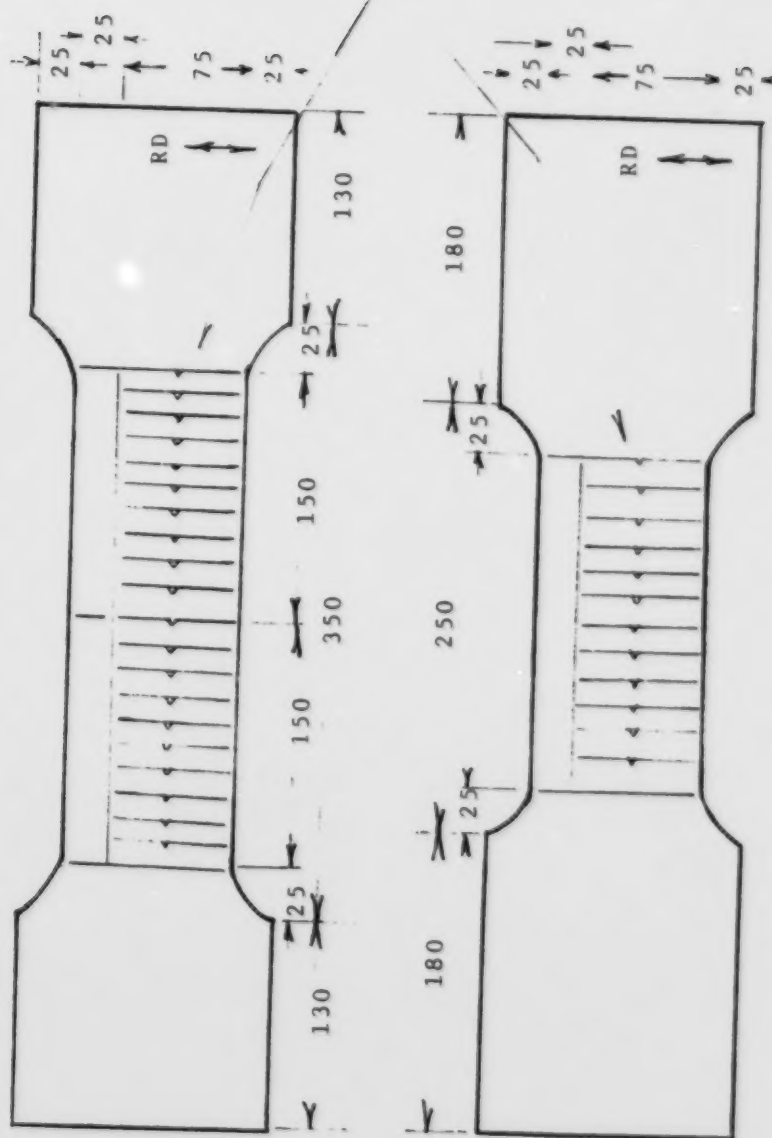


Figure 5. Specimens for cold forming and the locations of the tensile and Charpy blanks for the cold formed steels: (a) for steel X and (b) for steel Y.

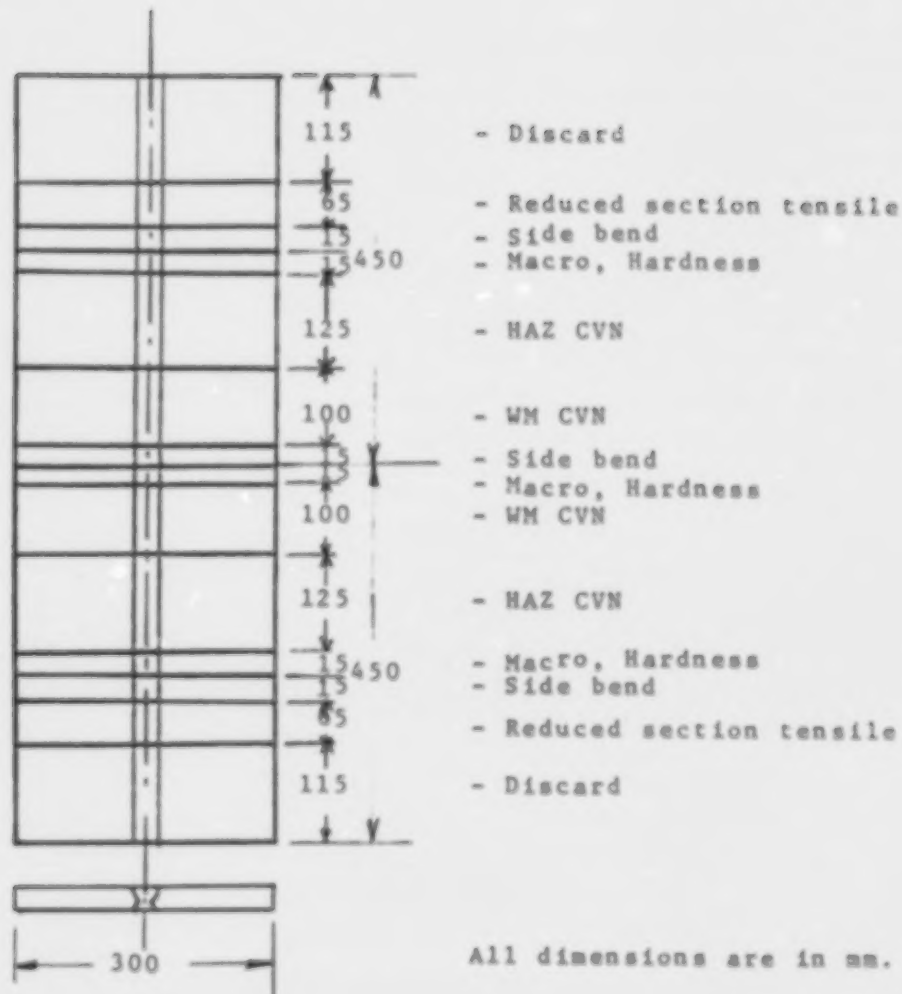
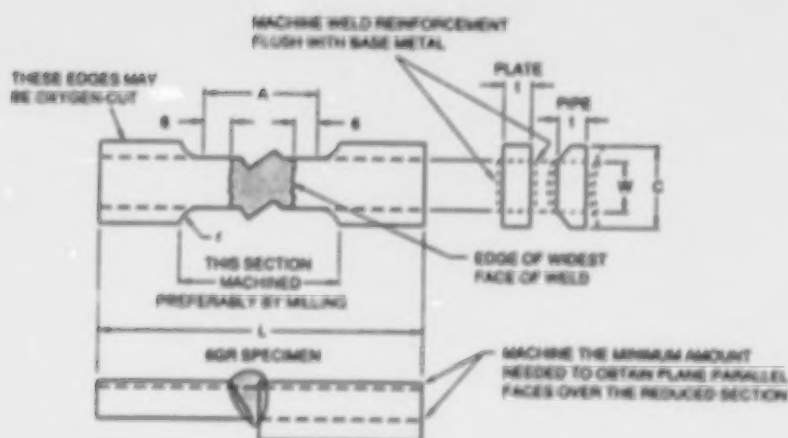


Figure 6. Locations of the weldment specimen blanks.

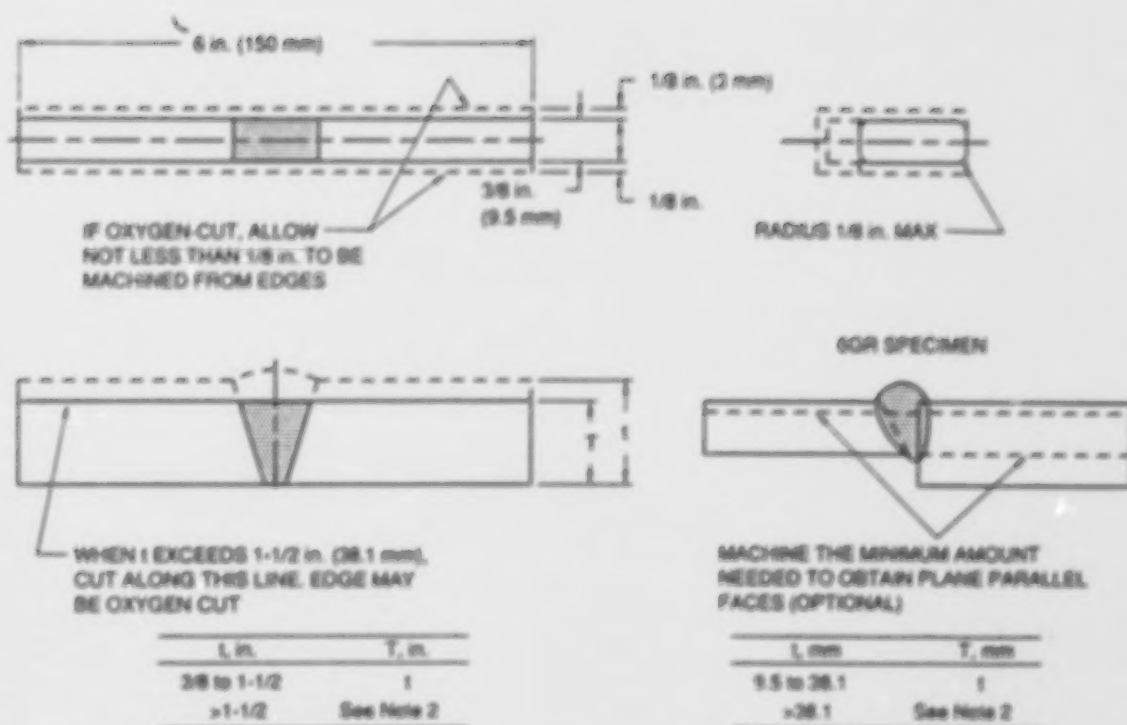


Dimensions in millimeters				
	Test plate			Test Pipe
	$T_p \leq 25.4$ mm	$25.4 < T_p < 38.1$ mm	$T_p \geq 38.1$ mm	50 mm & 75 mm diameter 150 mm & 200 mm diameter or larger job size pipe
A - Length of reduced section	Widest face of weld + 13 mm, 60 mm min			Widest face of weld + 13 mm, 60 mm min
L - Overall length, min (Note 2)	As required by testing equipment			As required by testing equipment
W - Width of reduced section (Notes 3, 4)	19 mm min	19 mm min	19 mm min	13 ± 25 mm 19 mm min
C - Width of grip section (Notes 4, 5)	W + 13 mm min	W + 13 mm min	W + 13 mm min	W + 13 mm min W + 13 mm min
t - Specimen thickness (Notes 6, 7)	T_p	T_p	T_p/n Note 7	Maximum possible with plane parallel faces within length A
r - Radius of fillet, mm min	13	13	13	25 25

Notes:

1. T_p = Nominal Thickness of the Plate.
2. It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.
3. The ends of the reduced section shall not differ in width by more than 0.102 mm. Also, there may be a gradual decrease in width from the ends to the center, but the width of either end shall not be more than 0.381 mm larger than the width at the center.
4. Narrower widths (W and C) may be used when necessary. In such cases, the width of the reduced section should be as large as the width of the material being tested permits. If the width of the material is less than W, the sides may be parallel throughout the length of the specimen.
5. For standard plate-type specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 6.35 mm.
6. The dimension t is the thickness of the specimen as provided for in the applicable material specifications. The minimum nominal thickness of 38 mm wide specimens shall be 4.8 mm except as permitted by the product specification.
7. For plates over 38 mm thick, specimens may be cut into approximately equal strips. Each strip shall be at least 19.0 mm thick. The test results of each strip shall meet the minimum requirements.
8. Due to limited capacity of some tensile testing machines, the specimen dimensions for Group IV and V steels in Table 4.1 may be as agreed upon by the Engineer and the Fabricator.

Figure 7. Dimensions of the reduced section tensile specimens.



Notes:

1. A longer specimen length may be necessary when using a wraparound type bending fixture or when testing steel with a yield strength of 90 ksi (620 MPa) or more.
2. For plates over 1-1/2 in. (38.1 mm) thick, cut the specimen into approximately equal strips with T between 3/4 in. (19.0 mm) and 1-1/2 in. and test each strip.
3. T = plate or pipe thickness.

Figure 8. Dimensions of the side bend specimen.

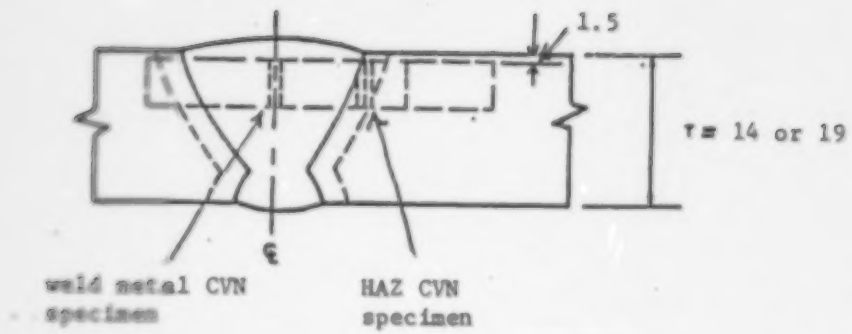


Figure 9. Notch locations of weld metal and HAZ Charpy specimens.

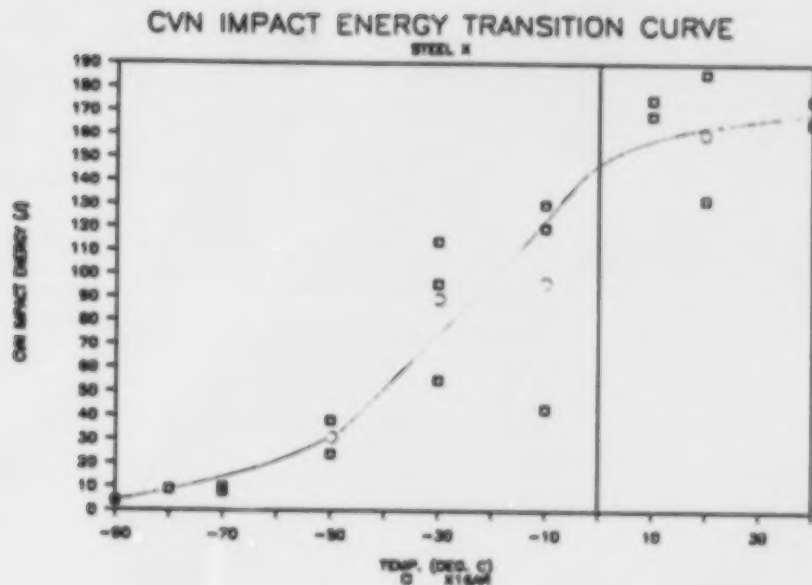


Figure 10. The longitudinal CVN impact energy transition curve for the as-received steel X (X16 AR).

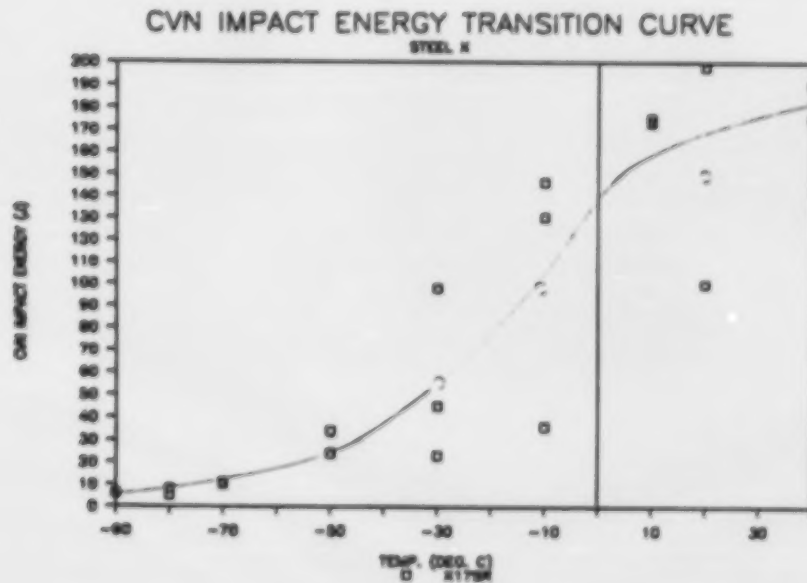


Figure 11. The longitudinal CVN impact energy transition curve for the stress relieved steel X (X17 SR).

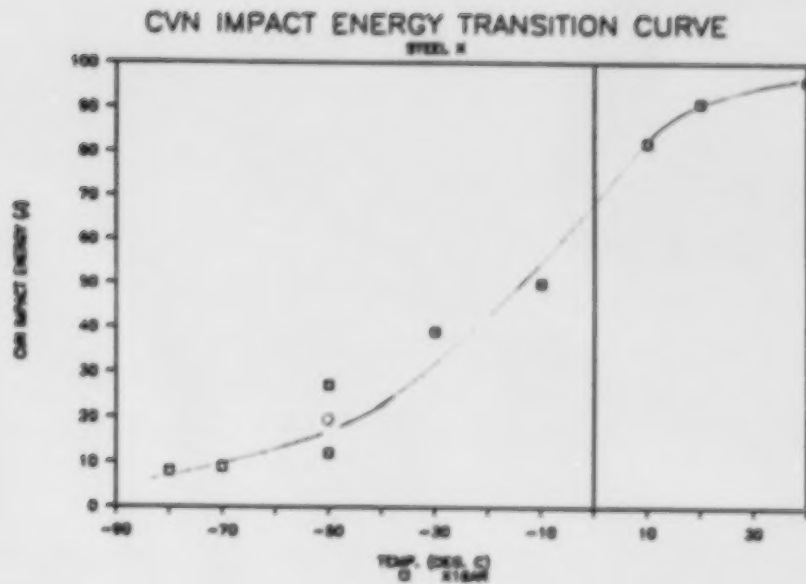


Figure 12. The transverse CVN impact energy transition curve for the as-received steel X (X18 AR).

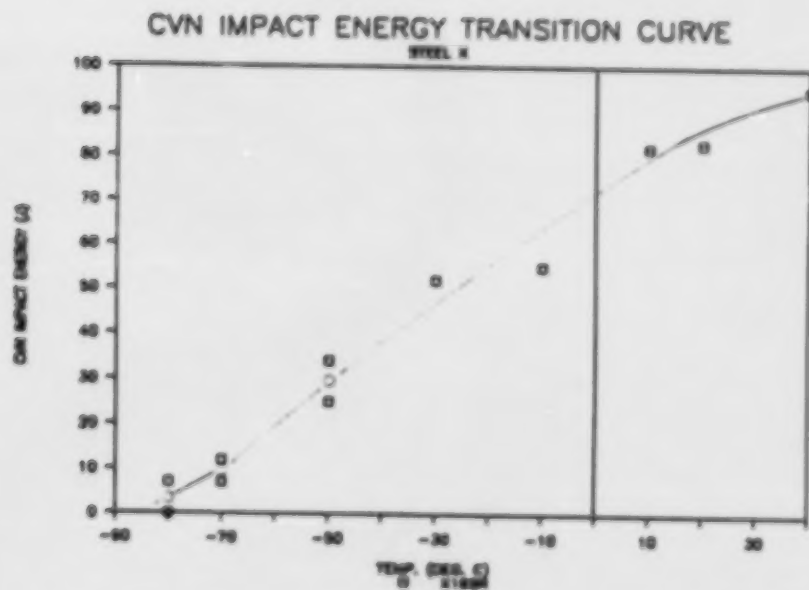


Figure 13. The transverse CVN impact energy transition curve for the stress relieved steel X (X18 SR).

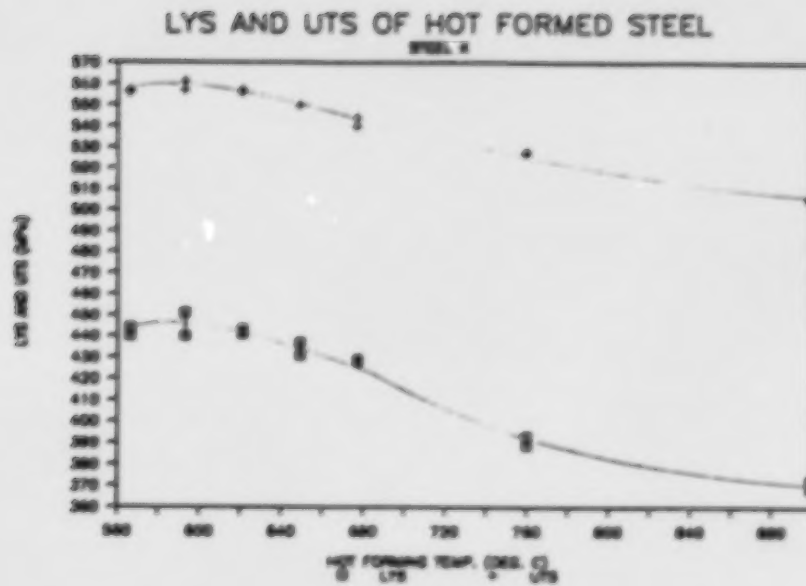


Figure 14. YS and UTS values versus hot forming temperatures of steel X.

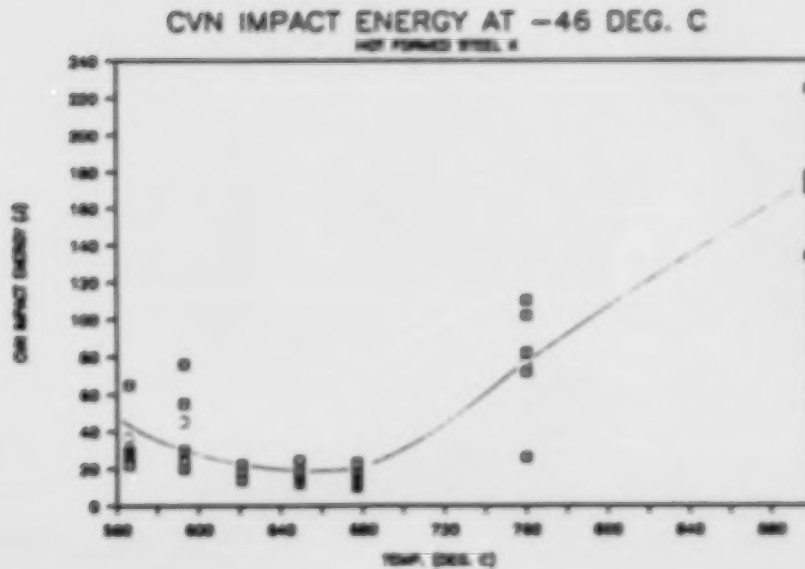


Figure 15. The longitudinal CVN impact energy values at -46° C versus hot forming temperatures plot for steel X.

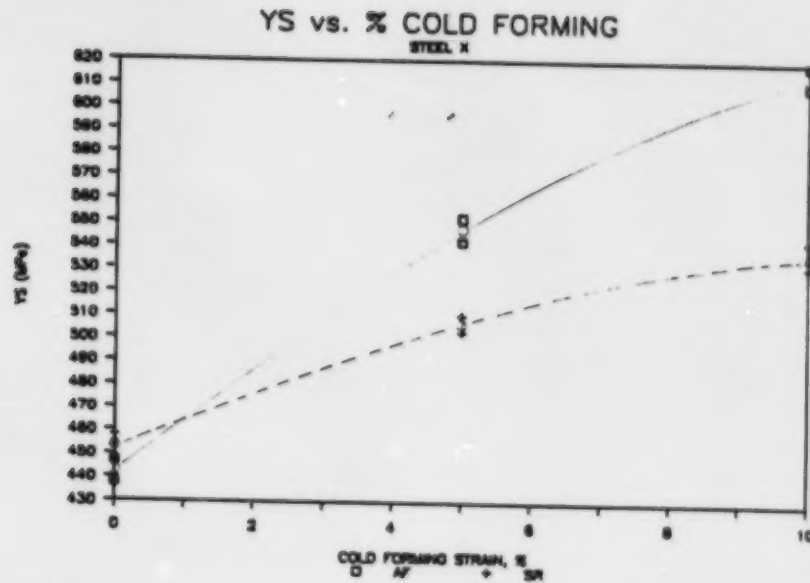


Figure 16. YS values in the as-formed and stress relieved conditions versus cold forming strain plot for steel X.

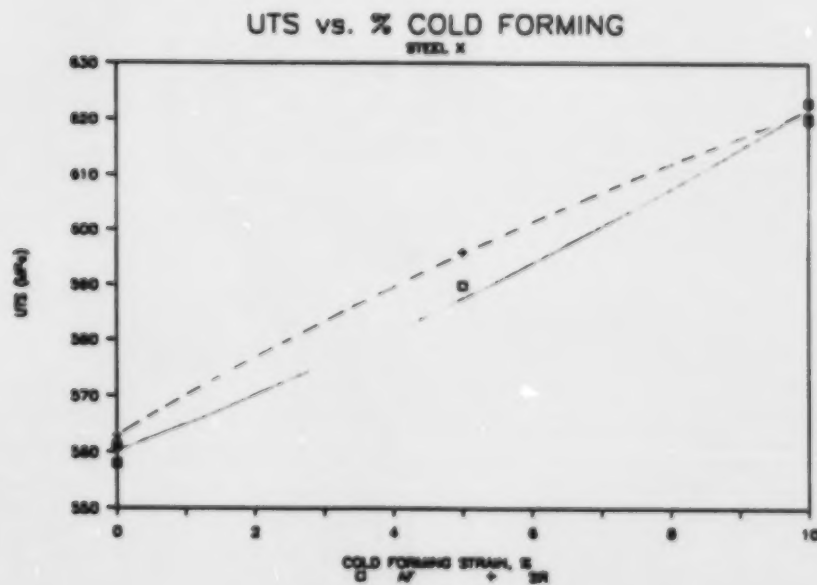


Figure 17. UTS values in the as-formed and stress relieved conditions versus cold forming strain plot for steel X.

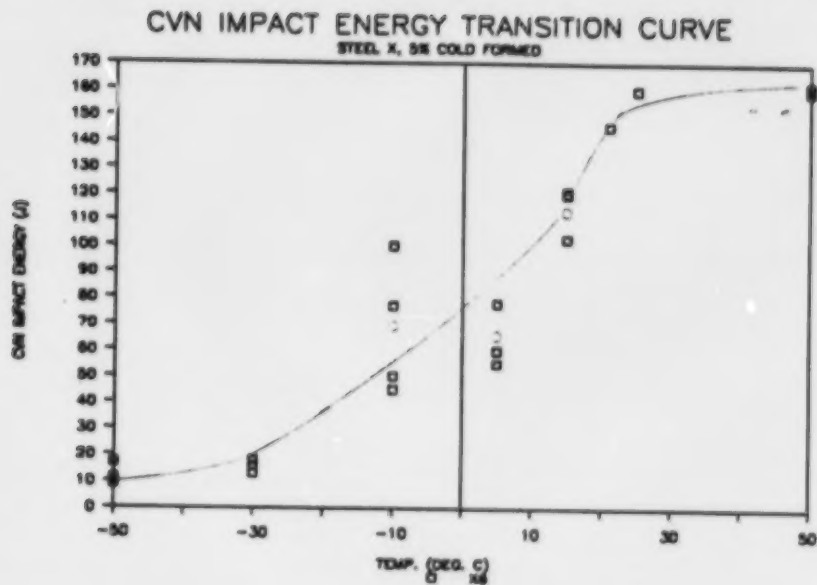


Figure 18. Longitudinal CVN impact energy transition curve for steel X cold formed to 5% tensile strain (X6).

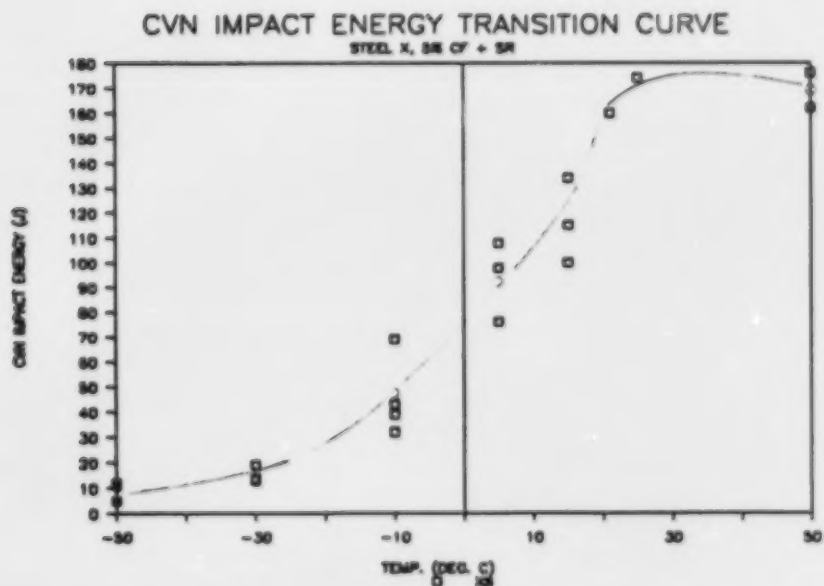


Figure 19. Longitudinal CVN impact energy transition curve for steel X cold formed to 5% tensile strain and stress relieved (X8).

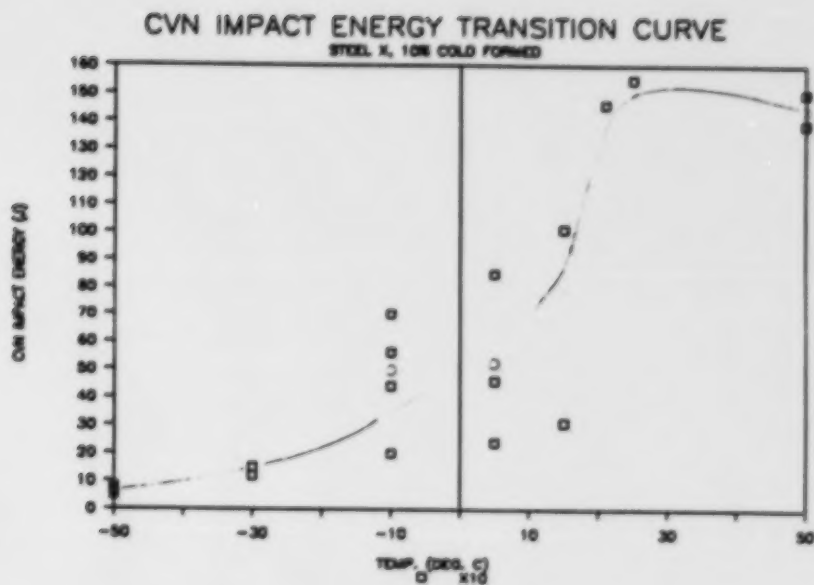


Figure 20. Longitudinal CVN impact energy transition curve for steel X cold formed to 10% tensile strain (X10).

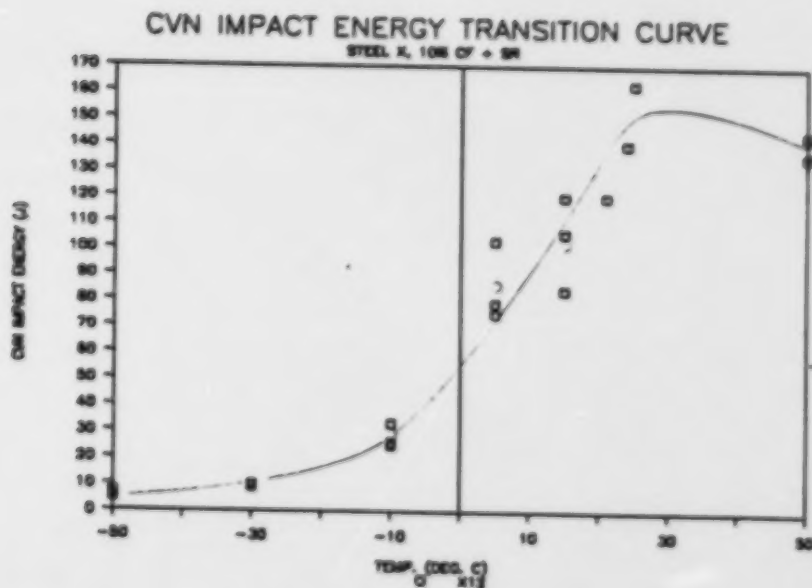


Figure 21. Longitudinal CVN impact energy transition curve for steel X cold formed to 10% tensile strain and stress relieved (X12).

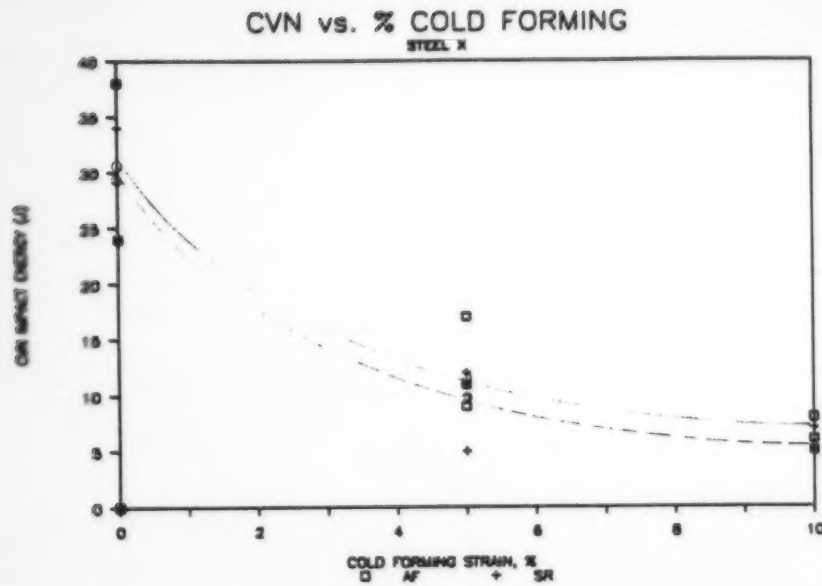


Figure 22. The CVN impact energy values at -46°C versus cold forming strain plot for steel X.

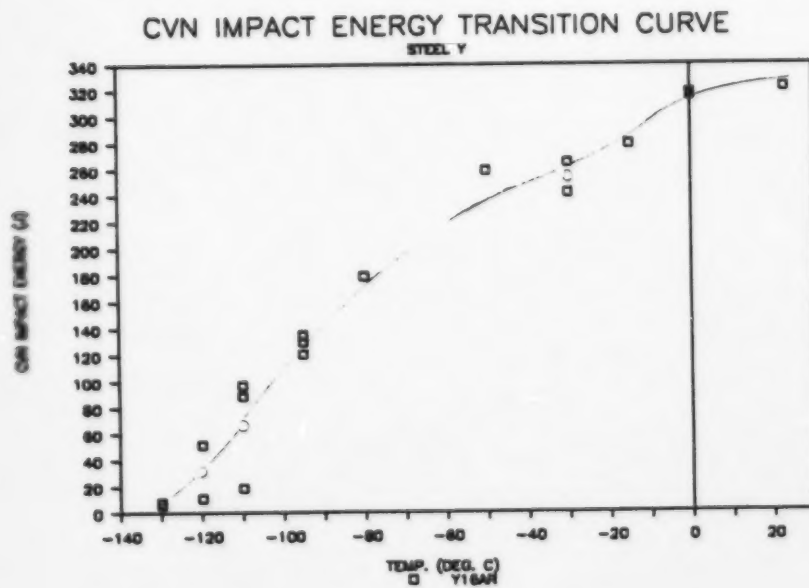


Figure 23. The longitudinal CVN impact energy transition curve for the as-received steel Y (Y16 AR).

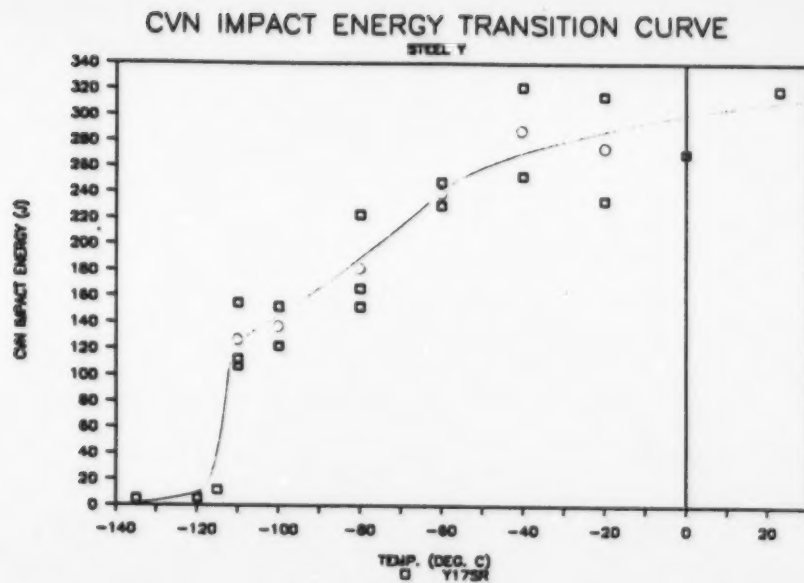


Figure 24. The longitudinal CVN impact energy transition curve for the stress relieved steel Y (Y17 SR).

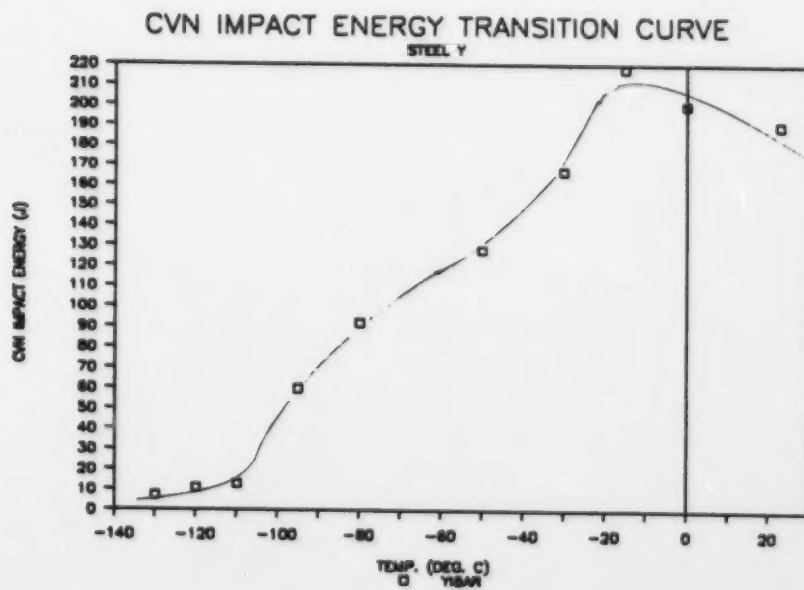


Figure 25. The transverse CVN impact energy transition curve for the as-received steel Y (Y18 AR).

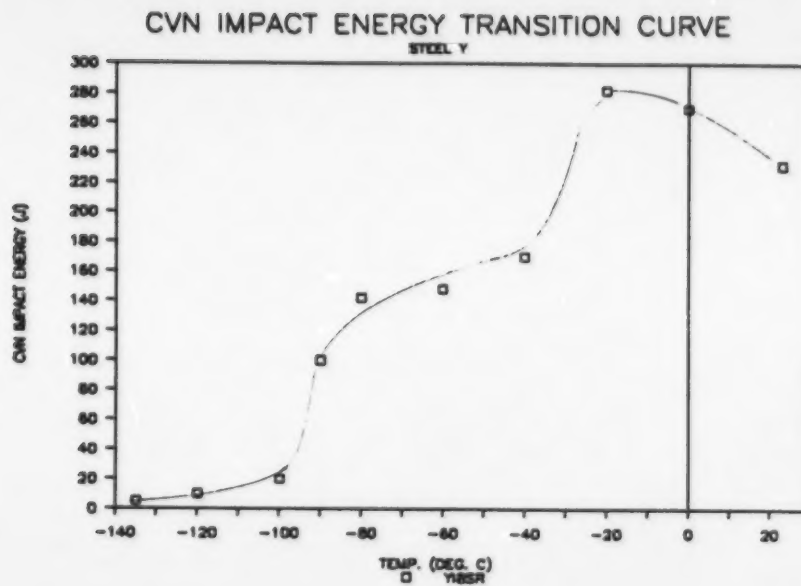


Figure 26. The transverse CVN impact energy transition curve for the stress relieved steel Y (Y18 SR).

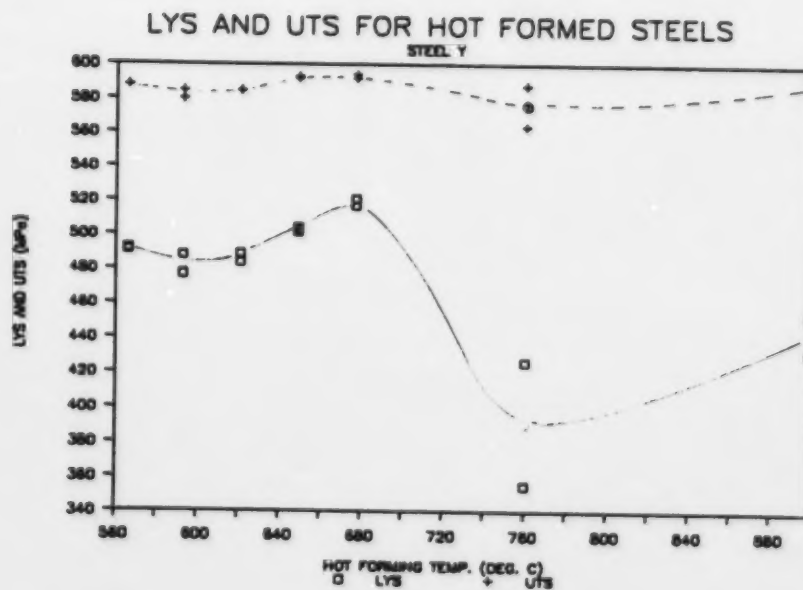


Figure 27. YS and UTS values versus hot forming temperatures plots for steel Y.

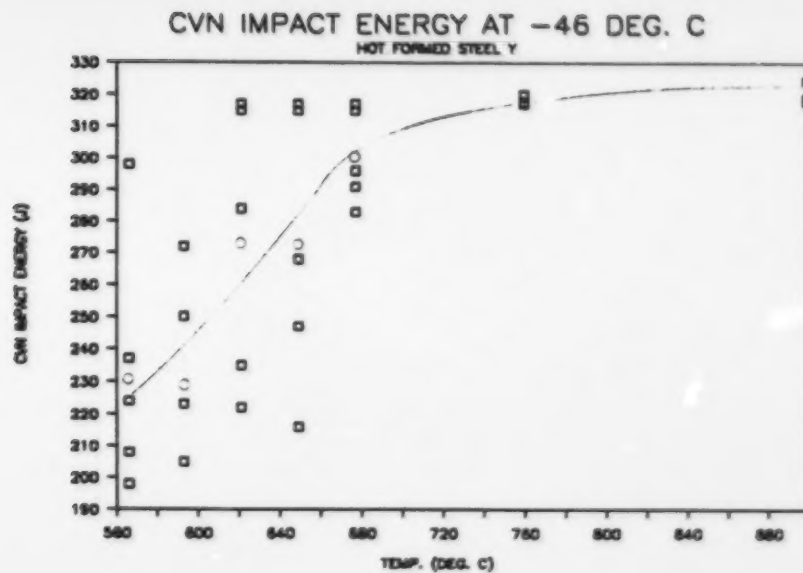


Figure 28. The longitudinal CVN impact energy values at -46° C versus hot forming temperatures plot for steel Y.

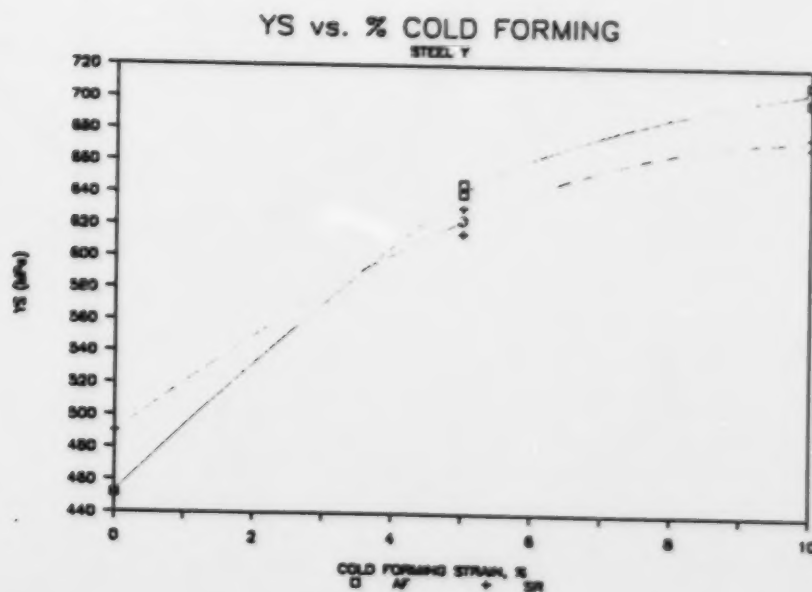


Figure 29. YS values in the as-formed and stress relieved condition versus cold forming strain plot for steel Y.

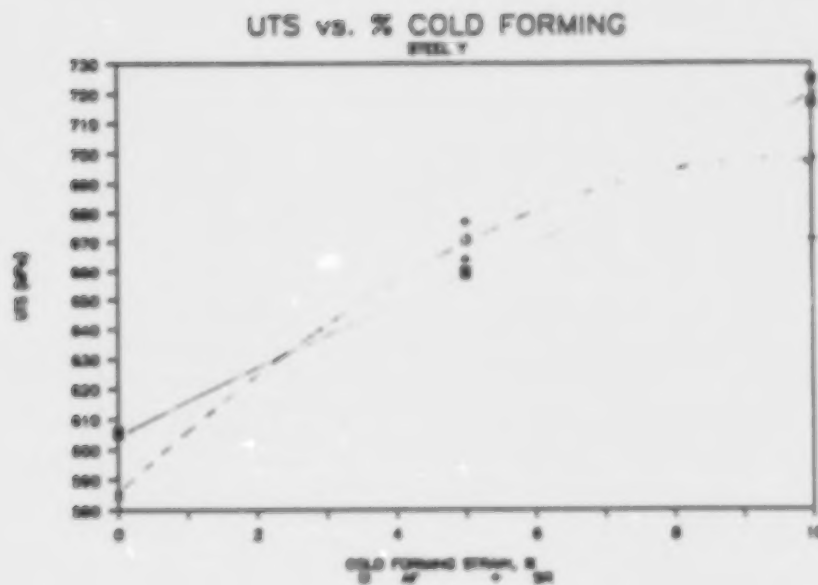


Figure 30. UTS values in the as-formed and stress relieved condition versus cold forming strain plot for steel Y.

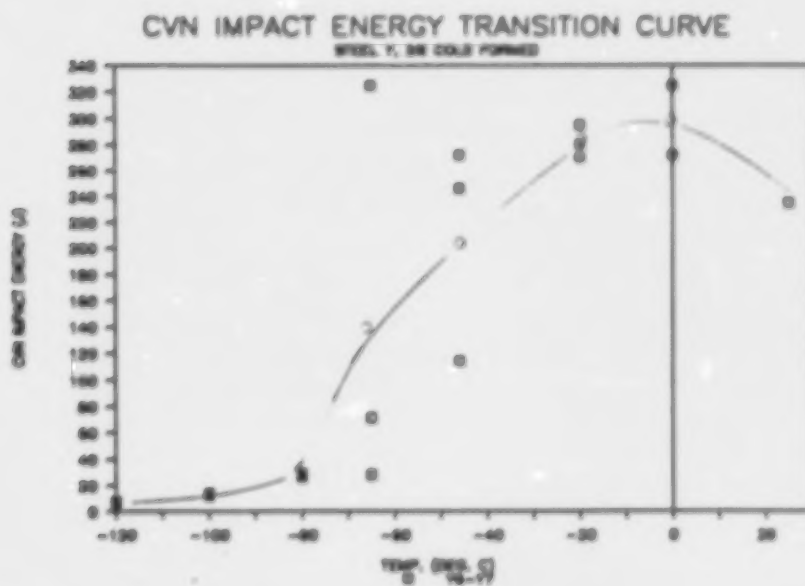


Figure 31. Longitudinal CVN impact energy transition curve for steel Y cold formed to 5% tensile strain (Y6-Y7).

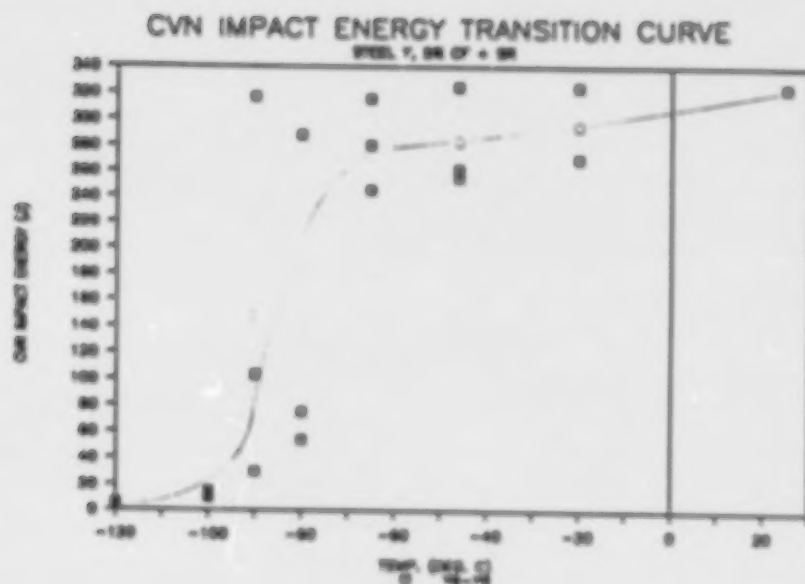


Figure 32. Longitudinal CVN impact energy transition curve for steel Y cold formed to 5% tensile strain and stress relieved (Y8-Y9).

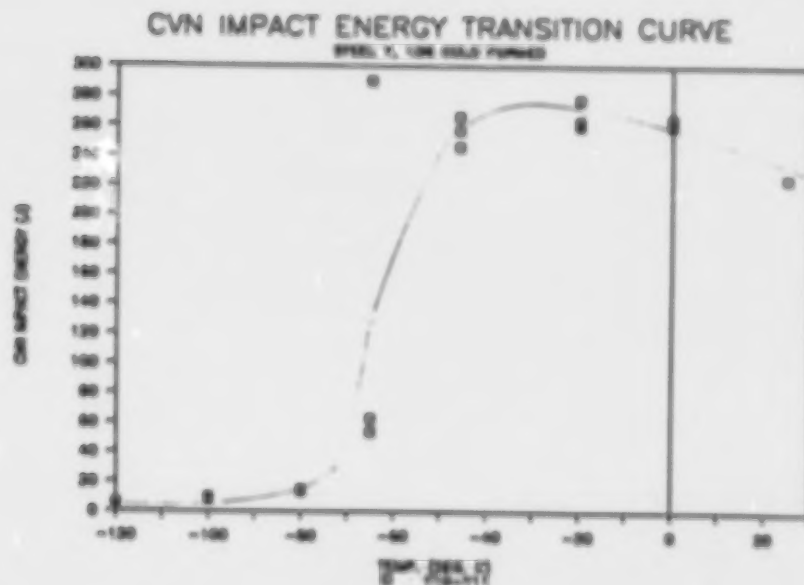


Figure 33. Longitudinal CVN impact energy transition curve for steel Y cold formed to 10% tensile strain (Y10-Y11).

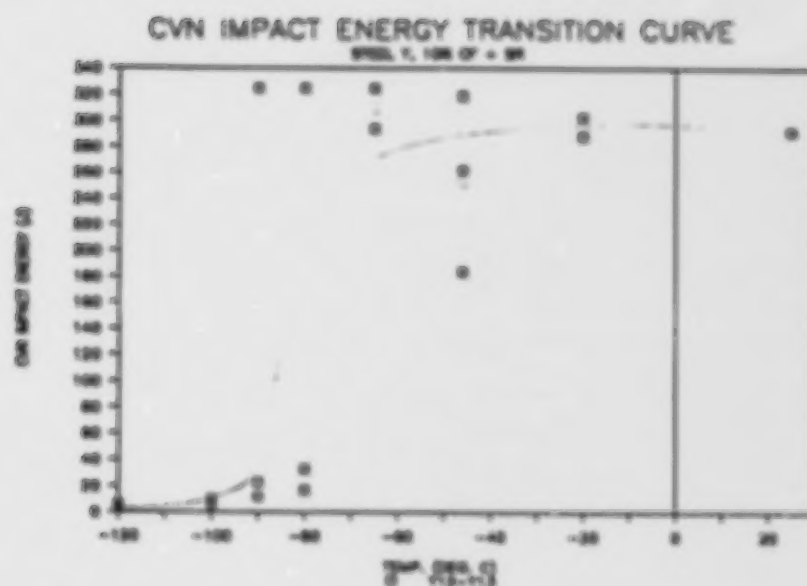


Figure 34. Longitudinal CVN impact energy transition curve for steel Y cold formed to 10% tensile strain and stress relieved (Y12-Y13).

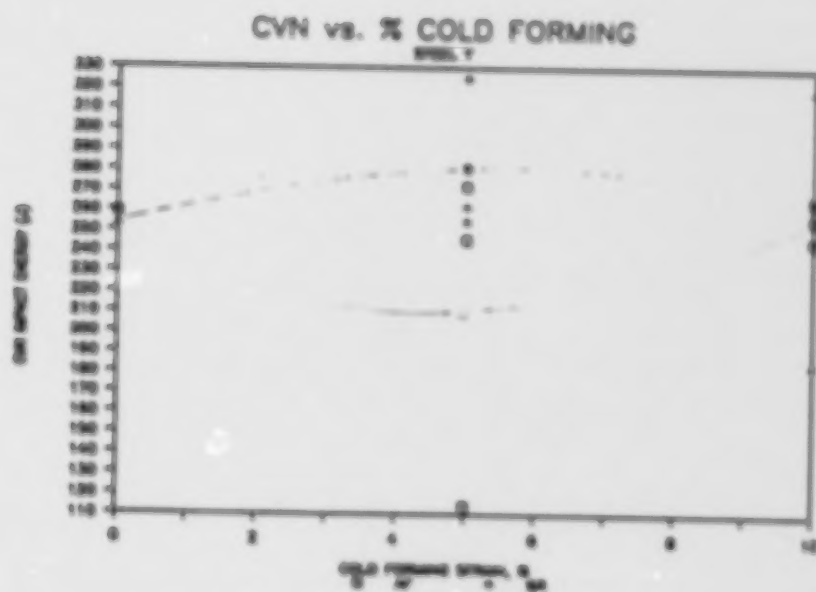


Figure 35. The CVN impact energy values at -46° C versus cold forming strain plot for steel Y.

APPENDIX - A

TEST RESULTS FOR STEEL X

- 1. Chemical Composition**
- 2. Base Plate Mechanical Tests**
- 3. Hot Forming Tests**
- 4. Cold Forming Tests**
- 5. Butt Weld Tests**



1. CHEMICAL COMPOSITION



Triodem
TECHNICAL SERVICES LTD.

2421 Drew Road, Mississauga, Ontario, Canada L5S 1A1
Tel. (416) 673-9899 Fax. (416) 673-8394

Customer: Welding Institute of Canada,
391 Burnhamthorpe Road, E.,
Oakville, Ontario.
L6J 6C9

Date: 15 May 1989.

Laboratory No. P-111

Attn: Mr. Sathish Rao Bala

Customer Order No. RD5554

Laboratory Report

Client's Material
Description:

Item X 1

TABLE A1

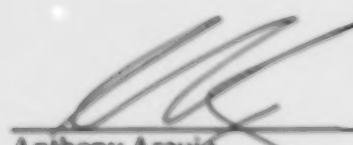
Test Performed

Result

1. Chemical Analysis (% by weight)

Carbon	0.11
Manganese	1.31
Phosphorus	0.019
Sulphur	0.006
Silicon	0.32
Chromium	0.030
Nickel	0.084
Molybdenum	<0.01
Copper	0.019
Vanadium	0.052
Aluminum	0.051
Niobium	0.034
Nitrogen	0.0035


C.A. Graham,
Chemical Analyst.


Anthony Araujo,
Laboratory Manager.

THIS REPORT IS FOR THE EXCLUSIVE AND PERSONAL USE OF THE CLIENT NAMED ABOVE AND MAY ONLY BE REPRODUCED BY WRITTEN PERMISSION FROM TRIODEM TECHNICAL SERVICES LTD. UNLESS OTHERWISE INSTRUCTED ANY SAMPLE PERTAINING TO THIS REPORT WILL BE DISCARDED 30 DAYS AFTER REPORT DATE. This report relates only to the sample(s) tested. Testing and inspection is only undertaken by Triodem Technical Services Ltd. subject to the express agreement that no liability or responsibility of any kind or however arising shall attach to Triodem Technical Services Ltd. or any employee of Triodem Technical Services Ltd. in respect of any loss, injury or damage arising directly or indirectly out of, or in connection with any such inspection or testing or any failure or omission at reported intervals.



Triodem
TECHNICAL SERVICES LTD.

2421 Drew Road, Mississauga, Ontario, Canada L5S 1A1
Tel. (416) 673-9899 Fax. (416) 673-8394

Customer: Welding Institute of Canada,
391 Burnhamthorpe Road, E.,
Oakville, Ontario.
L6J 6C9

Date: 15 May 1989.

Laboratory No. P-112

Attn: Mr. Sathish Rao Bala

Customer Order No. RD5554

Laboratory Report

Client's Material
Description:

Item x26

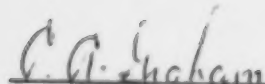
TABLE A2

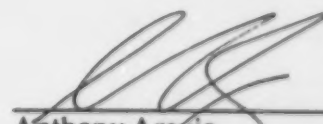
Test Performed

Result

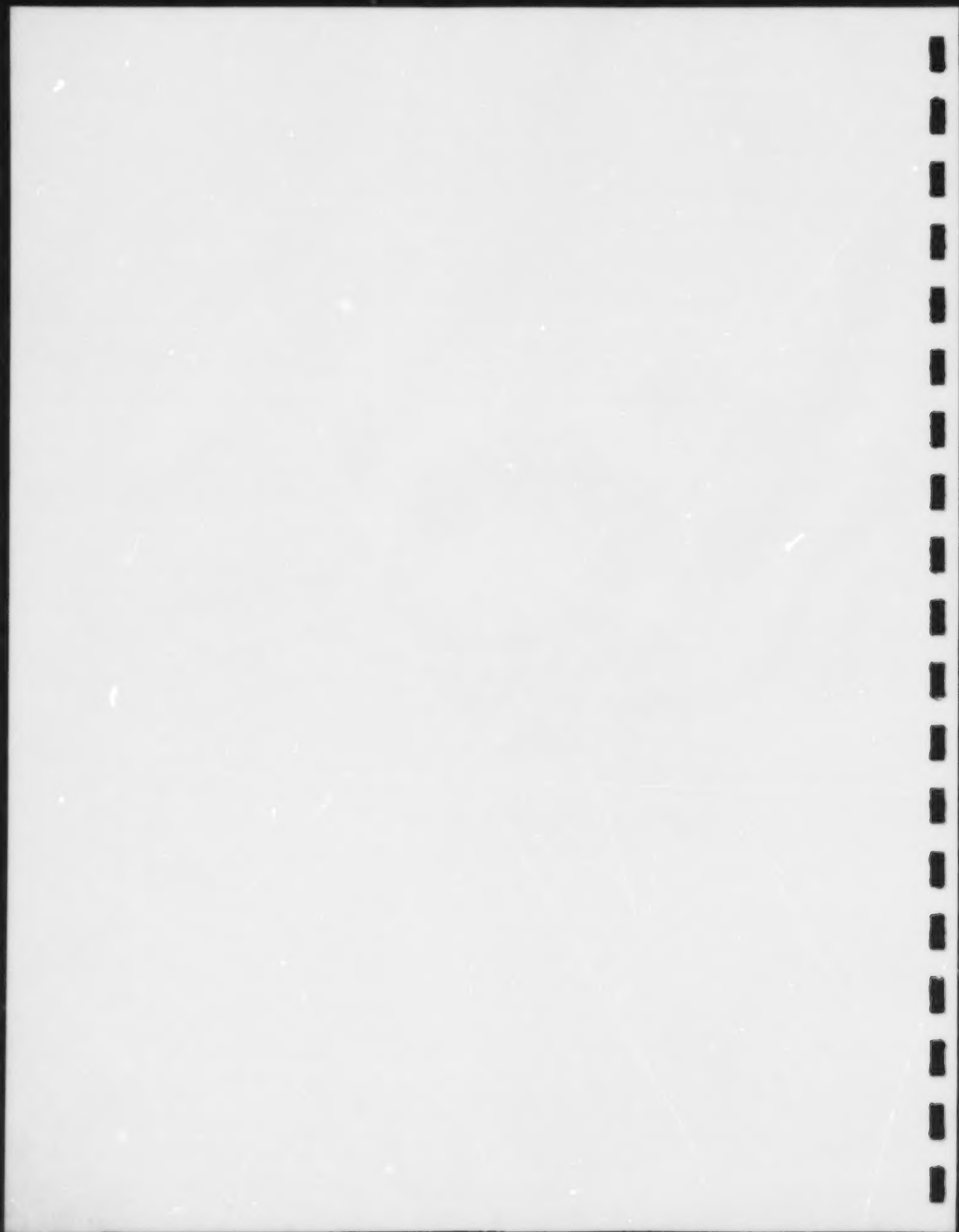
1. Chemical Analysis (% by weight)

Carbon	0.12
Manganese	1.31
Phosphorus	0.015
Sulphur	0.007
Silicon	0.32
Chromium	0.028
Nickel	0.086
Molybdenum	<0.01
Copper	0.015
Vanadium	0.050
Aluminum	0.051
Niobium	0.033
Nitrogen	0.0040


C.A. Graham,
Chemical Analyst.


Anthony Araujo,
Laboratory Manager.

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2. BASE PLATE MECHANICAL TESTS

Transverse Tensile Tests:

X15AR = As-received
X15SR = Stress relieved

Longitudinal CVN:

X16AR, X27AR = As-received
X17SR, X27SR = stress relieved

Lateral CVN:

X18AR = As-received
X18SR = Stress relieved

Table A3.

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel X, AR & SR

Test Standard: A-370

Specimens Machined by:

Specimen Number	15AR #1	15AR #2	15SR #1	15SR #2
Initial Thickness or Diameter (mm)	8.903	8.895	8.814	8.865
Initial Width (mm)				
Initial Cross-sectional Area (mm ²)	62.26	62.13	61.03	61.74
Initial Gauge Length (mm)	35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)				
Final Width (mm)				
Final Cross-sectional Area (mm ²)				
Final Gauge Length (mm)	47.50	48.26	46.23	46.74
Yield or Offset* Load (kN)	Upper	30.00	30.00	30.75
	0.2%	28.25	28.00	27.75
Maximum Load (kN)	34.95	34.67	34.35	34.70
Yield Strength (MPa)	Upper	482	483	504
	0.2%	454	450	455
Ultimate Tensile Strength (MPa)	561	558	563	562
Elongation (%)	33.6	35.7	30.0	31.4
Reduction of Area (%)				
Failure Location				

* Percentage of offset used to determine offset load: 0.1, 0.2, 0.5

Comments: Steel X

Lower YS (MPa) X15AR #1 = 438
 X15AR #2 = 447
 X15SR #1 = 458
 X15SR #2 = 448

Date:

Tested by:

Witnessed by:

Project Engineer: S.R.B.

Table A4.

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC 343

Specimen Material: Steel X

Test Standard: ASTM E23

(X16 AR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X16AR-1	R.T.		186			
-2	R.T.		132		70	4.04
-3	-10		120		70	3.79
-4	-10		130		70	4.06
-13	-10		43		20	2.97
-14	-30		96		50	3.81
-15	-30		114		50	3.94
-5	-30		55		10	3.28
-6	-50		38		10	3.00
-7	-50		24		10	2.79
-12	-70		10			
-8	-70		8		2	2.49
-9	-80		9		0	3.15
-10	-80		9		0	2.77
-11	-90		4		0	2.39
-12	-70		10		2	2.54
-16	+10		175		100	4.55
-17	+10		168		90	3.91
-18	+40		165		100	4.70
-19	+40		175		100	3.66

Comments: Steel X, as received

Date:

Longitudinal

Tested by:

Witnessed by:

Project Engineer: S.R.B.

Table A5

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC 343

Specimen Material: Steel X

Test Standard: ASTM E23

(X17 SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X17 SR-1	RT		198		100	4.37
-2	RT		100		50	3.86
-3	-10		146		65	4.22
-4	-10		130		70	3.96
-13	-10		36		20	3.10
-14	-30		98		45	3.94
-15	-30		45		20	3.18
-5	-30		23		20	2.79
-6	-50		34		20	3.00
-7	-50		24		8	2.85
-12	-70		11		5	2.57
-8	-70		10		0	2.54
-9	-80		5		0	2.34
-10	-80		8		2	2.52
-11	-90		6		0	2.41
-16	+10		173		90	4.04
-17	+10		175		90	4.7
-18	+40		175		100	4.17
-19	+40		190		100	4.62

Comments: Steel X, stress relieved
Longitudinal

Date:

Tested by:

Witnessed by:

Project Engineer: S.R.B.

Table A6.

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC 343

Specimen Material: Steel X

Test Standard: ASTM E23

(X18 AR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X18AR -1	RT		91		100	1.47
-2	-10		50		30	3.66
-8	-30		39		25	3.45
-3	-50		12		15	2.79
-4	-50		27		15	2.95
-7	-70		9		2	2.54
-5	-80		8		2	2.26
-6	-80		9		2	2.74
-9	+10		82		80	3.36
-10	+10		96		100	4.01

Comments: Steel X, as received
Transverse

Date:

Tested by:

Witnessed by:

Project Engineer: S.R.B.

Table A7.

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

(X18 SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X18SR-1	20		83		100	3.73
-2	-10		55		20	3.51
-8	-30		52		30	3.33
-3	-50		34		10	3.00
-4	-50		25		10	2.79
-7	-70		12		2	2.62
-5	-70		7		1	2.44
-6	-80		7		0	2.34
-9	+10		82		65	3.84
-10	+40		95		100	3.99

Comments: Steel X, stress relieved
Transverse

Date:

Tested by:

Witnessed by:

Project Engineer: S.R.B.

Table A8

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: Steel X

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

(X27AR & X27SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X27AR-1	-46		27		12	0.36
-2	-46		71		30	1.041
-3	-46		28		12	0.254
-4	-46		49		15	0.711
-5	-46		47		15	0.559
X27SR-1	-46		45		12	0.584
-2	-46		16		10	0.229
-3	-46		16		15	0.203
-4	-46		20		15	0.254
-5	-46		17		12	0.229

Comments: Steel X, as received & stress
relieved
Longitudinal

Date: January 1990

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.



3. HOT FORMING TESTS

Transverse Tensiles and Longitudinal CVN:

- X19 = Hot form at 566° C + stress relieve
- X20 = Hot form at 593° C + stress relieve
- X21 = Hot form at 621° C + stress relieve
- X22 = Hot form at 649° C + stress relieve
- X23 = Hot form at 677° C + stress relieve
- X24 = Hot form at 760° C + stress relieve
- X25 = Hot form at 899° C + stress relieve

Table A9.

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel X

Test Standard: A-370

X19 (566°C, SR); X20 (593°C, SR)

Specimen Number		X19-1	X19-2	X20-1	X20-2
Initial Thickness or Diameter (mm)		8.839	8.839	8.915	8.915
Initial Width (mm)					
Initial Cross-sectional Area (mm ²)		61.35	61.35	62.45	62.45
Initial Gauge Length (mm)		35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)					
Final Width (mm)					
Final Cross-sectional Area (mm ²)					
Final Gauge Length (mm)		47.24	46.99	48.01	46.23
Yield or Offset ^a Load (kN)	Upper	29.00	29.12	30.00	30.50
	0.2%	27.25	27.50	28.50	28.00
Maximum Load (kN)		34.20	27.50	35.05	34.80
Yield Strength (MPa)	Upper	472	474	481	489
	0.2%	444	448	457	449
Ultimate Tensile Strength (MPa)		557	556	561	557
Elongation (%)		32.9	32.1	35	30
Reduction of Area (%)					
Failure Location					

Comments: Steel X, hot formed

Date:

Lower YS (MPa)

Tested by:

X19-1 = 440

X19-2 = 444

Witnessed by:

X20-1 = 451

X20-2 = 440

Project Engineer: S.R.B.

Table A10.

Tensile Test Report

Client: Transport Canada

Client P.O. Number:

WIC Contract Number: RC-343

Test Standard: A-370

Specimen Standard:

Specimen Type:

Specimen Material: Steel X

X21 (621°C, SR); X22 (649°C, SR)

Specimen Number	X21-1	X21-2	X22-1	X22-2
Initial Thickness or Diameter (mm)	8.87	8.89	8.87	8.89
Initial Width (mm)				
Initial Cross-sectional Area (mm ²)	61.74	62.06	61.74	62.06
Initial Gauge Length (mm)	35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)				
Final Width (mm)				
Final Cross-sectional Area (mm ²)				
Final Gauge Length (mm)	47.50	47.50	47.50	46.99
Yield or Offset ^a Load (kN)	Upper 0.2%	29.30 27.62	30.00 27.87	29.25 27.50
Maximum Load (kN)		34.38	34.50	33.92
Yield Strength (MPa)	Upper 0.2%	475 448	483 449	474 445
Ultimate Tensile Strength (MPa)		557	556	550
Elongation (%)		33.6	33.6	32.1
Reduction of Area (%)				
Failure Location				

Comments: Steel X, hot formed

Lower YS (MPa)

X21-1 = 441

X21-2 = 443

X22-1 = 437

X22-2 = 431

Date:

Tested by:

Witnessed by:

Project Engineer: S.R.B.

Table All.

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel X

Test Standard: A-370

X23 (677°C, SR); X24 (760°C, SR)

Specimen Number		X23-1	X23-2	X24-1	X24-2
Initial Thickness or Diameter (mm)		8.890	8.915	8.890	8.915
Initial Width (mm)					
Initial Cross-sectional Area (mm ²)		62.06	62.45	62.06	62.45
Initial Gauge Length (mm)		35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)					
Final Width (mm)					
Final Cross-sectional Area (mm ²)					
Final Gauge Length (mm)		47.50	47.50	47.50	48.26
Yield or Offset* Load (kN)	Upper	29.80	28.75	25.00	26.88
	0.2%	27.15	27.00	24.43	24.65
Maximum Load (kN)		33.50	33.98	32.75	32.87
Yield Strength (MPa)	Upper	480	461	403	430
	0.2%	437	432	394	395
Ultimate Tensile Strength (MPa)		540	544	528	527
Elongation (%)		33.6	33.6	33.6	35.7
Reduction of Area (%)					
Failure Location					

Comments: Steel X, hot formed

Date:

Lower YS (MPa)

X23-1 = 429

X23-2 = 428

X24-1 = 389

X24-2 = 393

Tested by:

Witnessed by:

Project Engineer: S.R.B.

Table A12.

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel X

Test Standard: A-370

X25 (899°C, SR)

Specimen Number	X25-1	X25-2		
Initial Thickness or Diameter (mm)	8.915	8.865		
Initial Width (mm)				
Initial Cross-sectional Area (mm ²)	62.45	61.74		
Initial Gauge Length (mm)	35.56	35.56		
Final Thickness or Diameter (mm)				
Final Width (mm)				
Final Cross-sectional Area (mm ²)				
Final Gauge Length (mm)	49.78	48.01		
Yield or Offset* Load (kN)	Upper 0.2%	25.05 23.25	25.00 23.30	
Maximum Load (kN)		31.50	31.25	
Yield Strength (MPa)	Upper 0.2%	401 372	405 378	
Ultimate Tensile Strength (MPa)		505	506	
Elongation (%)		40	35	
Reduction of Area (%)				
Failure Location				

Comments: Steel X, hot formed
 Lower YS (MPa)
 X25-1 = 369
 X25-2 = 373

Date:

Tested by:

Witnessed by:

Project Engineer: S.R.B.

Table A13

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

566°C, SR (X19)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X19-1 -2	-46 -46		26 30		8 8	0.20 0.48
-3	-46		28		10	0.36
-4	-46		65		20	0.97
-5	-46		22		8	0.38

Comments: Steel X, Hot Formed

Date: July 6, 1990

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A14

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

593°C, SR (X20)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X20-1 -2	-46 -46		76 20		20 8	1.14 0.25
-3	-46		30		10	0.46
-4	-46		24		8	0.33
-5	-46		55		15	0.81

Comments: Steel X, hot formed

Date: July 6, 1990

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A15

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

621°C, SR (X21)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X21-1 -2	-46 -46		14 22		7 10	0.20 0.33
-3	-46		14		8	0.20
-4	-46		14		8	0.20
-5	-46		18		10	0.30

Comments: Steel X, hot formed

Date: July 6, 1989

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A16

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

649°C, SR (X22)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X22-1 -2	-46 -46		12 15		5 8	0.13 0.23
-3	-46		19		8	0.28
-4	-46		24		8	0.36
-5	-46		14		8	0.18

Comments: Steel X, hot formed

Date: July 6, 1989

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A17

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

677°C, SR (X23)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X23-1 -2	-46 -46		12 15		3 3	0.15 0.18
-3	-46		18		5	0.31
-4	-46		23		8	0.36
-5	-46		10		3	0.10

Comments: Steel X, hot formed

Date: July 6, 1989

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A18

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

760°C, SR (X24)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X24-1 -2	-46 -46		72 102		20 25	1.02 1.42
-3	-46		26		15	0.41
-4	-46		110		30	1.55
-5	-46		82		25	1.17

Comments: Steel X, hot formed

Date: July 6, 1989

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A19

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

899°C, SR (X25)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X25-1 -2	-46 -46		134 170		60 65	1.83 2.13
-3	-46		225		90	1.91
-4	-46		178		65	2.13
-5	-46		174		65	1.98

Comments: Steel X, hot formed

Date: July 6, 1989

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

4. COLD FORMING TESTS

Transverse Tensiles and Longitudinal CVN:

- X6 = 5% cold formed (as-formed)
- XF = 5% cold formed + stress relieved
- X10 = 10% cold formed (as-formed)
- X12 = 10% cold formed + stress relieved

Table A20.

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel X

Test Standard: A-370

X6(5% cold formed)

X10(10% cold formed)

Specimen Number	X6AR-1	X6AR-2	X10AR-1	X10AR-2
Initial Thickness or Diameter (mm)	8.94	8.923	8.92	8.96
Initial Width (mm)				
Initial Cross-sectional Area (mm ²)	62.77	62.52	62.52	62.97
Initial Gauge Length (mm)	35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)				
Final Width (mm)				
Final Cross-sectional Area (mm ²)				
Final Gauge Length (mm)	45.72	45.72	43.69	42.16
Yield or 'Offset' Load (kN) Upper 0.2%	34.00	34.50	38.13	39.00
Maximum Load (kN)	37.00	36.88	38.75	39.25
Yield Strength (MPa) Upper 0.2%	542	552	610	619
Ultimate Tensile Strength (MPa)	590	590	620	623
Elongation (%)	28.5	28.5	23	18.5
Reduction of Area (%)				
Failure Location				

Comments: Steel X, cold formed

Date: Aug./89

No yield points

Tested by: I.M.

Witnessed by:

Project Engineer: S.R.B.

Table A21.

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel X

Test Standard: A-370

X8 (5% cold formed - stress relieved)

X12 (10% cold formed - stress relieved)

Specimen Number		X8SR-1	X8SR-2	X12SR-1	X12SR-2
Initial Thickness or Diameter (mm)		8.89	8.93	8.94	8.96
Initial Width (mm)					
Initial Cross-sectional Area (mm ²)		62.06	62.65	62.77	63.10
Initial Gauge Length (mm)		35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)					
Final Width (mm)					
Final Cross-sectional Area (mm ²)					
Final Gauge Length (mm)		45.97	46.23	44.70	44.20
Yield or Offset ^a Load (kN)	Upper	33.13	33.37	36.12	36.23
	0.2%	31.88	31.75	34.25	34.50
Maximum Load (kN)		37.00	37.37	39.00	39.12
Yield Strength (MPa)	Upper	534	532	576	575
	0.2%	521	507	545	547
Ultimate Tensile Strength (MPa)		596	596	621	621
Elongation (%)		29	30	25.5	24.5
Reduction of Area (%)					
Failure Location					

Comments: Steel X, cold formed & stress relieved

Date: Aug 1989

Lower YS (MPa)

X8SR-1 = 510

X8SR-2 = 503

X12SR-1 = 532

X12SR-2 = 543

Tested by: I.M.

Witnessed by:

Project Engineer: S.R.B

Table A22

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

X6 (5% Cold Formed)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X6-1	25		160		95	1.85
-2	-10		45		15	0.66
-3	-10		100		60	1.42
-4	-10		77		55	1.04
-5	-30		18		5	0.15
-6	-30		13		5	0.15
-7	-30		16		5	0.15
-8	-50		11		5	0.00
-9	-50		17		1	0.13
-10	-50		9		1	0.00
-11	+5		55		40	0.76
-12	+5		78		45	1.07
-13	+5		60		40	0.91
-14	+15		120		90	1.60
-15	+15		103		70	1.32
-16	+15		121		70	1.42
-17	21		146		98	2.01
-18	50		162		100	2.18
-19	50		162		100	2.11
-20	-10		50		20	0.66

Comments: Longitudinal
cold formed

Date: August 1989

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A23

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

X8 (5% Cold Formed + SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X8-1	25		174		100	2.31
-2	-10		69		30	1.14
-3	-10		43		15	0.76
-4	-10		32		15	0.53
-5	-30		14		5	0.28
-6	-30		19		5	0.36
-7	-30		13		5	0.25
-8	-50		11		1	0.00
-9	-50		5		1	0.00
-10	-50		12		1	0.03
-11	+5		108		65	1.55
-12	+5		98		60	1.45
-13	+5		76		50	1.17
-14	+15		100		75	1.45
-15	+15		115		80	1.68
-16	+15		134		90	1.98
-17	+50		162		100	2.13
-18	+50		176		98	1.91
-19	21		160		95	1.78
-20	-10		39		15	0.69

Comments: Longitudinal

Date: Aug. 1989

cold formed & stress relieved

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A24

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

X10 (10% Cold Formed)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X10-1	25 (RT)		155		100	1.65
-2	-10		56		15	0.74
-3	-10		70		20	0.97
-4	-10		20		8	0.20
-5	-30		15		2	0.18
-6	-30		12		4	0.13
-7	-30		12		2	0.13
-8	-50		5		0	0.03
-9	-50		6		0	0.03
-10	-50		8		0	0.03
-11	+5		85		50	1.09
-12	+5		46		30	0.61
-13	+5		24		20	0.30
-14	+15		101		70	1.25
-15	+15		101		70	1.25
-16	+15		31		30	0.53
-17	21 (RT)		146		100	1.58
-18	50		139		100	1.52
-19	50		150		100	1.73
-20	-10		44		20	0.61

Comments: Cold Formed
Longitudinal

Date: Aug./89

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A25

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

X12 (10% Cold Formed + SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
X12-1	25 (RT)		163		95	1.75
-2	-10		33		10	0.56
-3	-10		25		8	0.46
-4	-10		26		10	0.33
-5	-30		9		4	0.15
-6	-30		10		3	0.13
-7	-30		10		4	0.15
-8	-50		7		0	0.03
-9	-50		5		0	0.00
-10	-50		7		0	0.00
-11	+5		103		75	1.47
-12	+5		79		65	1.27
-13	+5		75		40	1.12
-14	+15		120		60	1.50
-15	+15		84		60	1.30
-16	+15		106		85	1.65
-17	21 (RT)		120		95	1.65
-18	+50		144		100	2.16
-19	+50		136		95	1.75
-20	24 (RT)		140		98	1.70

Comments: Cold Formed & Stress Relieved

Date: Aug./89

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.



5. BUTT WELD TESTS

Hardness Profiles, Bend Tests, Reduced Section Tensiles, HAZ CVN, Weld Metal CVN:

XHA = High heat input, as-welded

XHS = High heat input, stress relieved

XLA = Low heat input, as-welded

XLS = Low heat input, stress relieved

WELDING DATA SHEET

WELDING INSTITUTE OF CANADA
INSTITUT DE SOUDAGE DU CANADA

CONTRACT NO. RC 343

DATA SHEET NO. 1

PROCESS: SMAW

MATERIALS: STEEL X

POSITION: Flat (1G)

PREHEAT:

Preheat Temp. 120 deg. C (250 deg. F)

Interpass Temp. 150 deg. C (300 deg. F)

Preheat Maintenance

FILLER METAL:

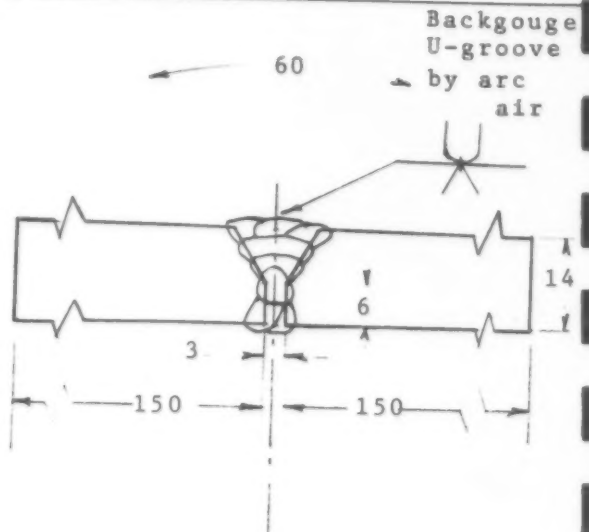
Classification E 55018-C1 (8018-C1)

Trade Name CLA Atom Arc 8018-C1

FLUX:

Class:

Trade Name:



Weld length = 915 mm
JOINT DETAILS

GAS COMPOSITION REQUIRED:

Shielding Gas At CFH
Backing Gas At CFH
Trailing Gas At CFH

ELECTRICAL CHARACTERISTICS:

Power Source: Lincoln DCRP 500
Current Type: DC
Polarity: RP

SPECIAL NOTES

Reverse side backgouged

Weld ID

XLA - Procor T 8913 = as-welded

XLS - Procor T 8914 = stress relieved

T	WELD SEQUENCE			ELECTRODE		WELDING VARIABLES					
	SIDE	LAYER	PASS	TYPE	SIZE mm	AMPS	VOLTS	E.S.O.	SPEED mmps	WFS ipm	HEAT INPUT
	1	1	1	55018-	3	120	24		2		1.4 kJ/mm
	1	2	2	C1	4	140	24		2		1.4 kJ/mm
	1	3	3	,,	4	140	24		2		1.4 kJ/mm
	1	3	4	,,	4	140	24		2		1.4 kJ/mm
	1	3	5	,,	4	140	24		2		1.4 kJ/mm
	Backgouged										
	2	1	6	,,	4	140	24		2		1.4 kJ/mm
	2	2	7	,,	4	140	24		2		1.4 kJ/mm
	2	2	8	,,	4	140	24		2		1.4 kJ/mm
ISSUED BY:				DATE:		LAB TECHNOLOGIST:					

WELDING DATA SHEET

CONTRACT NO. RC 343

DATA SHEET NO. 2

WELDING INSTITUTE OF CANADA
INSTITUT DE SOUDAGE DU CANADA



PROCESS: SAW - Twin wire

MATERIALS: STEEL X

POSITION: Flat (1G)

PREHEAT:

Preheat Temp. 150 deg.C (300 deg.F)

Interpass Temp.

Preheat Maintenance

FILLER METAL:

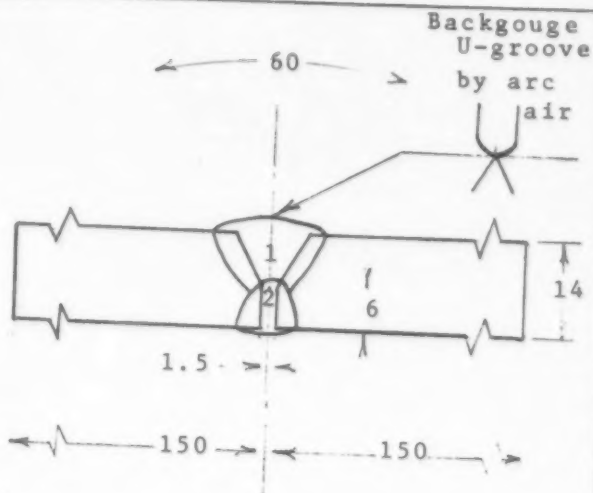
Classification

Trade Name Lincoln L56 Wire

FLUX:

Class:

Trade Name: Lincoln 880M



Weld length = 915 mm

JOINT DETAILS

GAS COMPOSITION REQUIRED:

Shielding Gas

At

CFH

Backing Gas

At

CFH

Trailing Gas

At

CFH

ELECTRICAL CHARACTERISTICS:

Power Source: Lincoln DCRP1000

Current Type: DC

Polarity: RP

SPECIAL NOTES

Reverse side backgouged

Weld ID

XHA - Procor T 8915 = as-welded

XHS - Procor T 8916 = stress relieved

T	WELD SEQUENCE			ELECTRODE		WELDING VARIABLES					
	SIDE	LAYER	PASS	TYPE	SIZE mm	AMPS	VOLTS	E.S.O. mm	SPEED mmps	WFS ipm	HEAT INPUT
	1	1	1	L56 Twin	2.4/2.4	850	30	32	6.8	69.4	3.8 kJ/mm
	Backgouged										
	2	1	1	,,	,,	850	30	32	6.8	69.4	3.8 kJ/mm
ISSUED BY:				DATE:		LAB TECHNOLOGIST:					

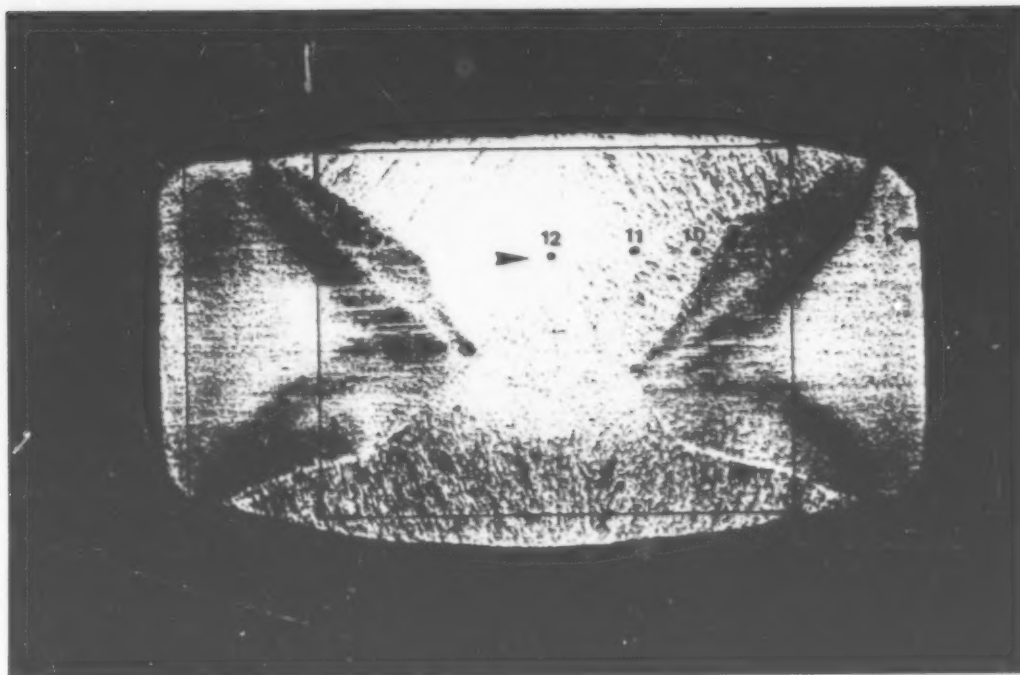


Figure A1. Weldment XHA-1.

Table A26. Microhardness Survey of Weldment XHA-1.

Location	HV ₁₀₀₀
1 - PM	202
2 - PM	198
3 - HAZ	184
4 - HAZ	191
5 - HAZ	207
6 - HAZ	219
7 - HAZ	213
8 - HAZ	224
9 - HAZ	225
10 - WM	216
11 - WM	217
12 - WM	219

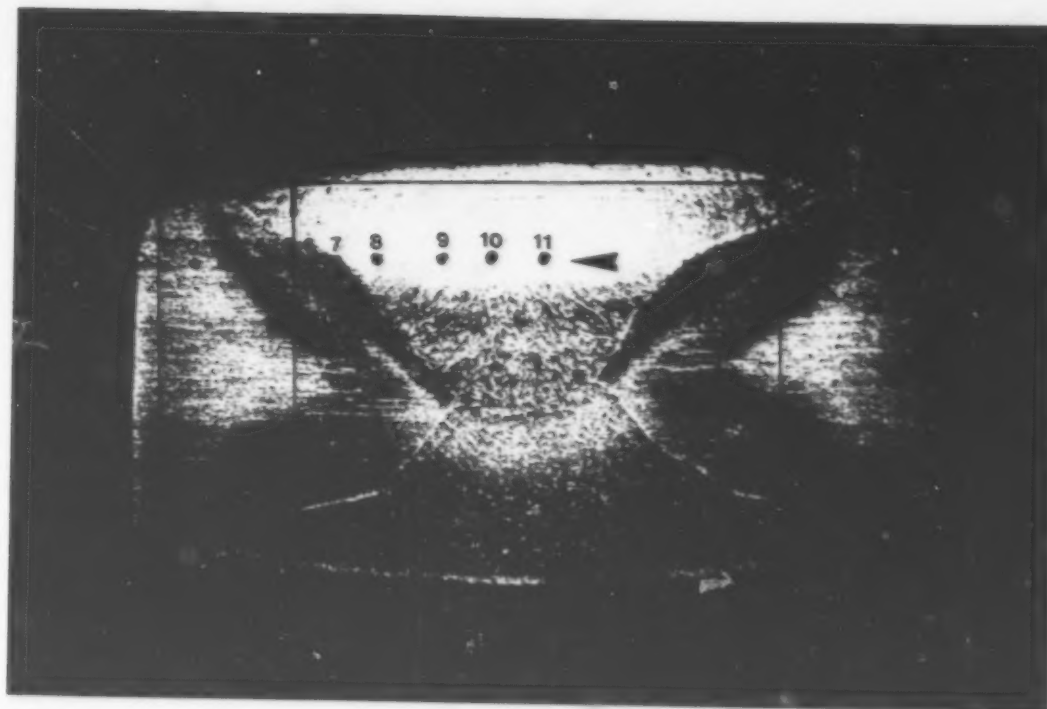


Figure A2. Weldment XHA-2.

Table A27. Microhardness Survey of Weldment XHA-2.

Location	HV ₁₀₀₀
1 - PM	194
2 - PM	195
3 - HAZ	188
4 - HAZ	206
5 - HAZ	214
6 - HAZ	215
7 - HAZ	224
8 - WM	210
9 - WM	214
10 - WM	212
11 - WM	210

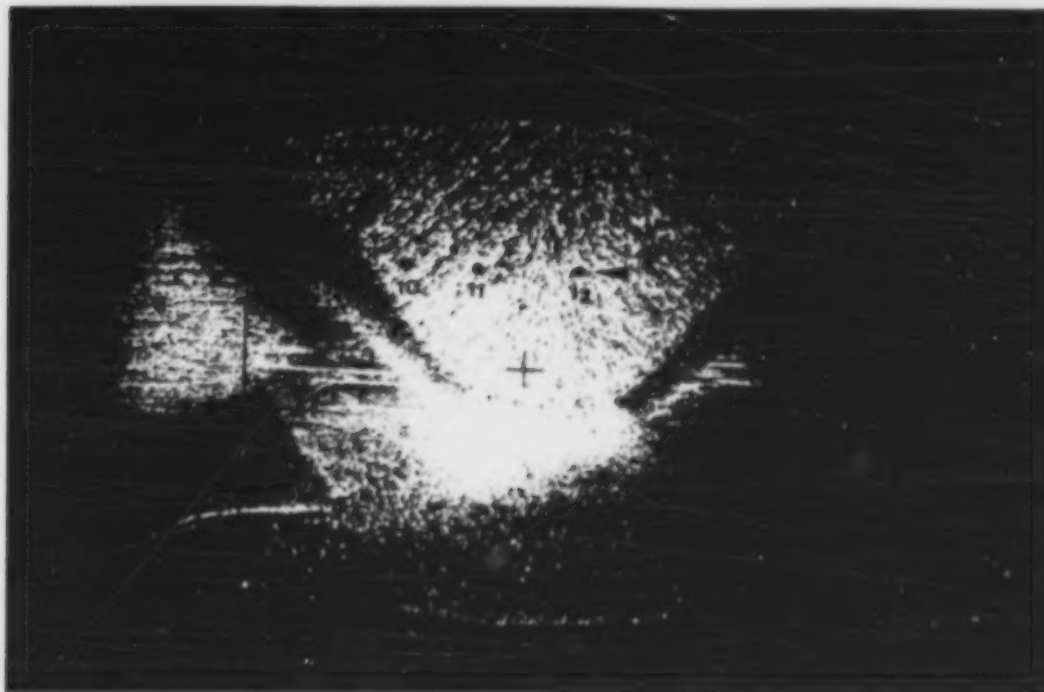


Figure A3. Weldment XHA-3.

Table A28. Microhardness Surveys of Weldment XHA-3.

Location	HV ₁₀₀₀
1 - PM	192
2 - PM	180
3 - PM	190
4 - HAZ	189
5 - HAZ	185
6 - HAZ	218
7 - HAZ	213
8 - HAZ	215
9 - HAZ	221
10 - WM	204
11 - WM	211
12 - WM	210

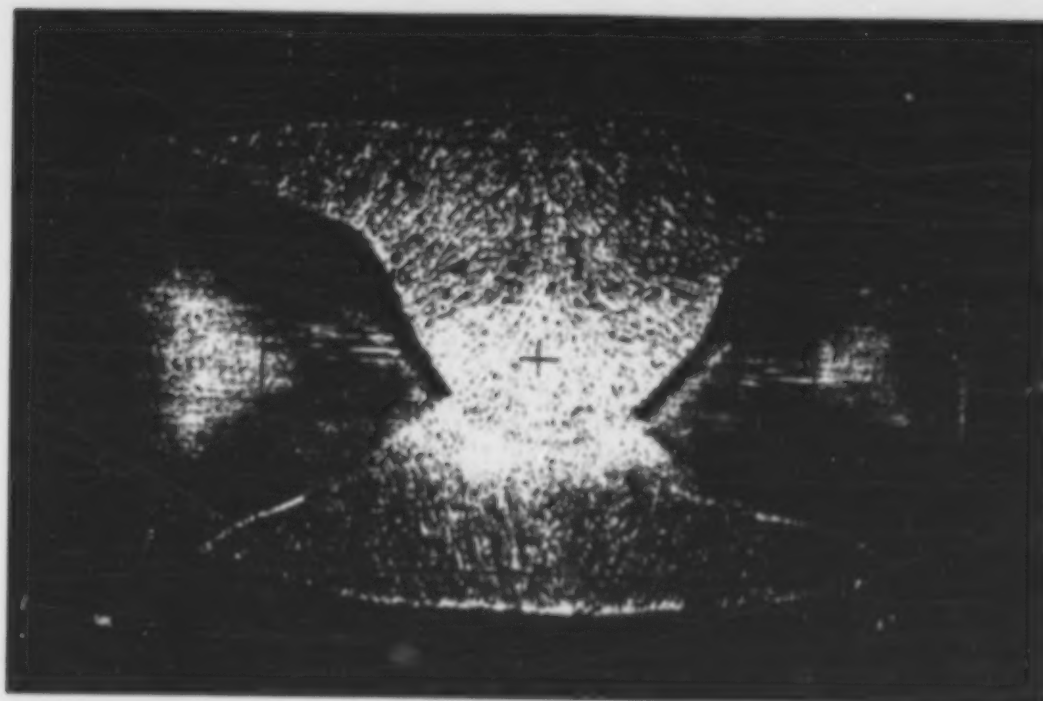


Figure A4. Weldment XHA-4.

Table A29. Microhardness Survey of Weldment XHA-4.

Location	HV _{0.05}
1 - PM	188
2 - HAZ	179
3 - HAZ	187
4 - HAZ	185
5 - HAZ	199
6 - HAZ	212
7 - HAZ	208
8 - HAZ	213
9 - HAZ	214
10 - WM	207
11 - WM	208
12 - WM	210

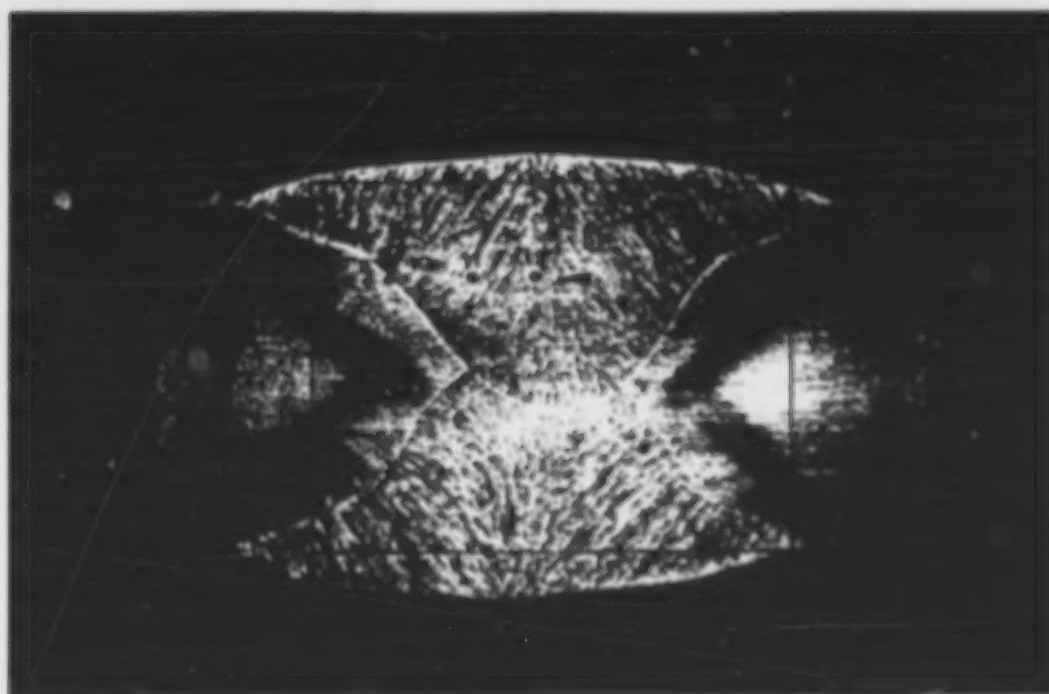


Figure A5. Weldment XHS-1.

Table A30. Microhardness Survey of Weldment XHS-1.

Location	HV ₁₀₀
1 - PM	195
2 - PM	188
3 - HAZ	180
4 - HAZ	181
5 - HAZ	211
6 - HAZ	229
7 - HAZ	230
8 - HAZ	240
9 - HAZ	241
10 - WM	214
11 - WM	214
12 - WM	225

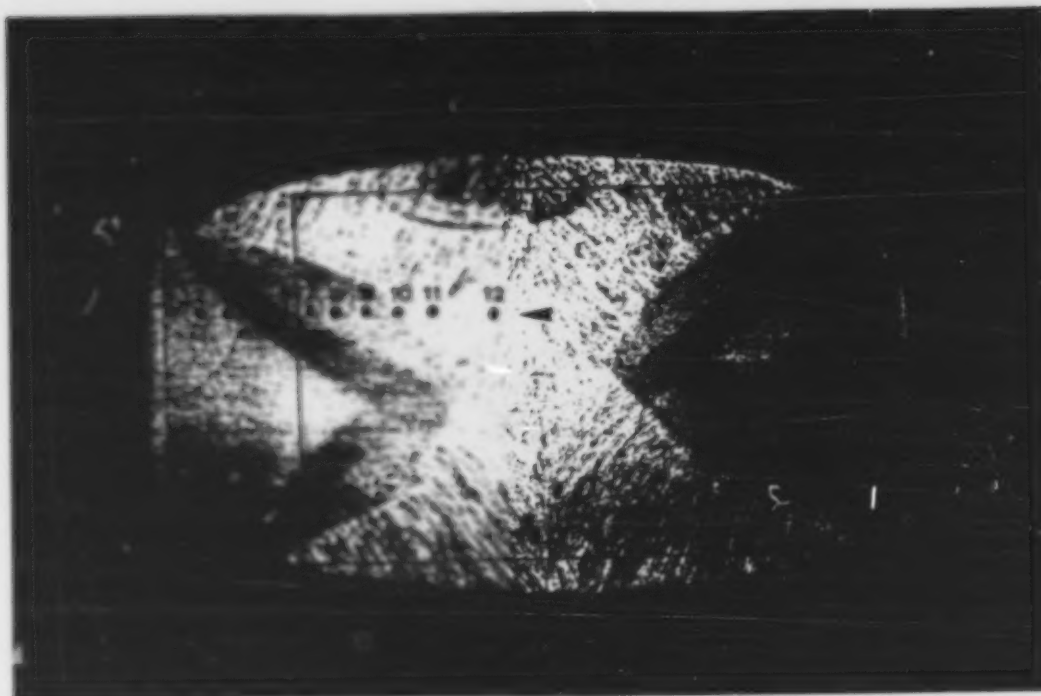


Figure A6. Weldment XHS-2.

Table A31. Microhardness Survey of Weldment XHS-2.

Location	HV ₁₀₀₀
1 - PM	185
2 - PM	180
3 - HAZ	173
4 - HAZ	192
5 - HAZ	193
6 - HAZ	212
7 - HAZ	226
8 - HAZ	235
9 - HAZ	227
10 - WM	229
11 - WM	220
12 - WM	218

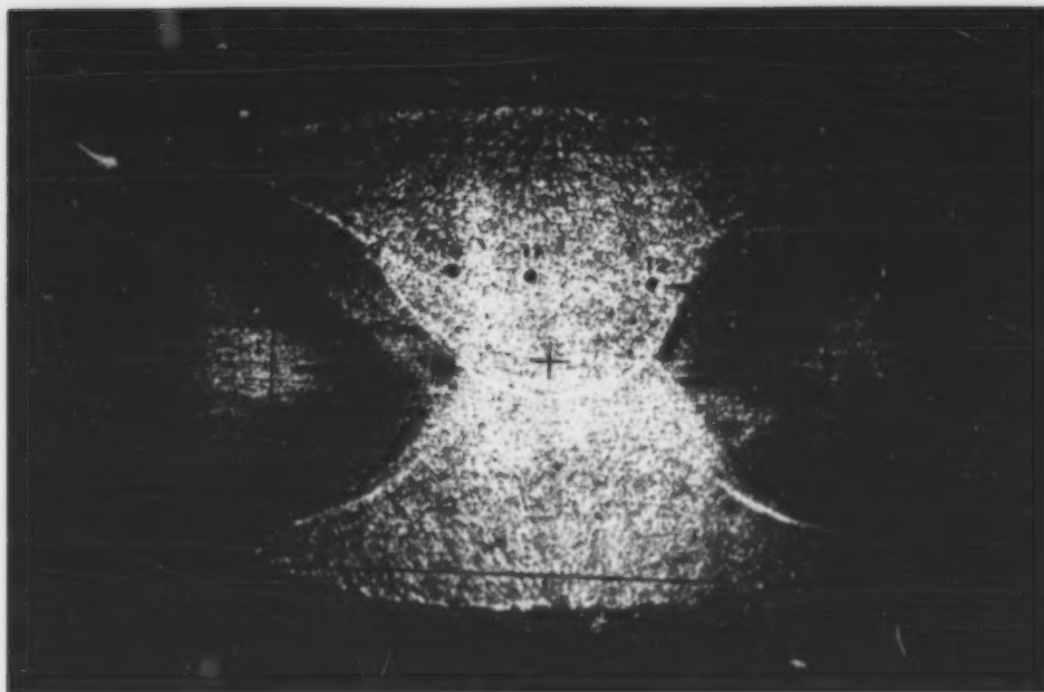


Figure A7. Weldment XHS-3.

Table A32. Microhardness Survey of Weldment XHS-3.

Location	HV ₁₀₀₀
1 - PM	184
2 - HAZ	184
3 - HAZ	172
4 - HAZ	179
5 - HAZ	197
6 - HAZ	218
7 - HAZ	222
8 - HAZ	228
9 - HAZ	233
10 - WM	223
11 - WM	216
12 - WM	216

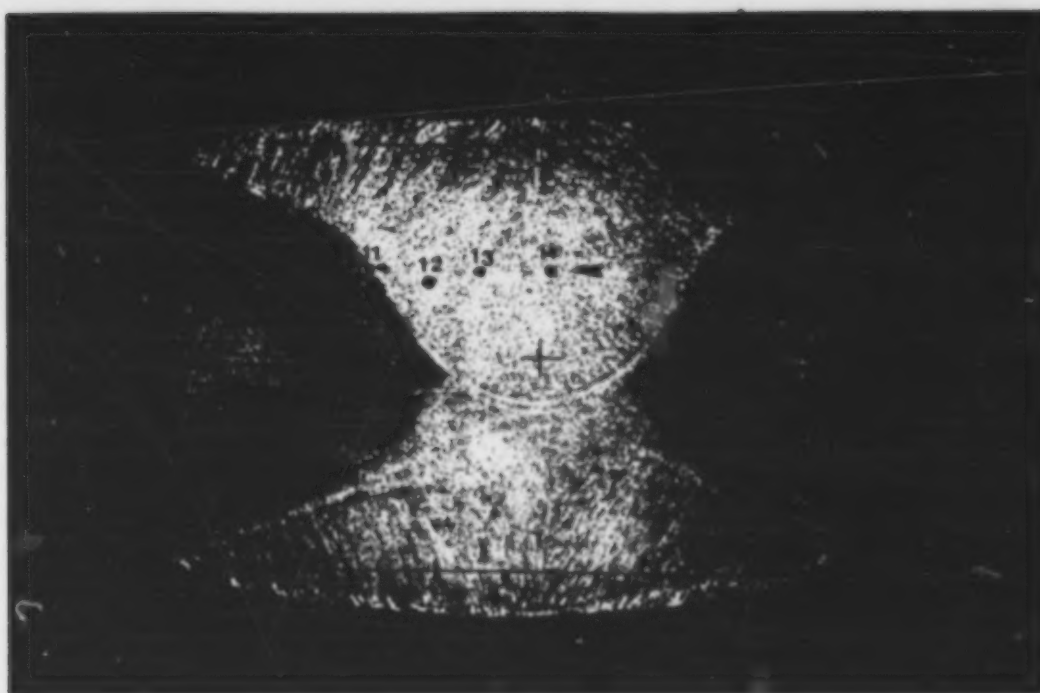


Figure A8. Weldment XHS-4.

Table A33. Microhardness Survey of Weldment XHS-4.

Location	HV ₁₀₀₀
1 - PM	160
2 - PM	177
3 - PM	175
4 - HAZ	176
5 - HAZ	182
6 - HAZ	181
7 - HAZ	196
8 - HAZ	208
9 - HAZ	219
10 - HAZ	232
11 - HAZ	242
12 - WM	219
13 - WM	208
14 - WM	214

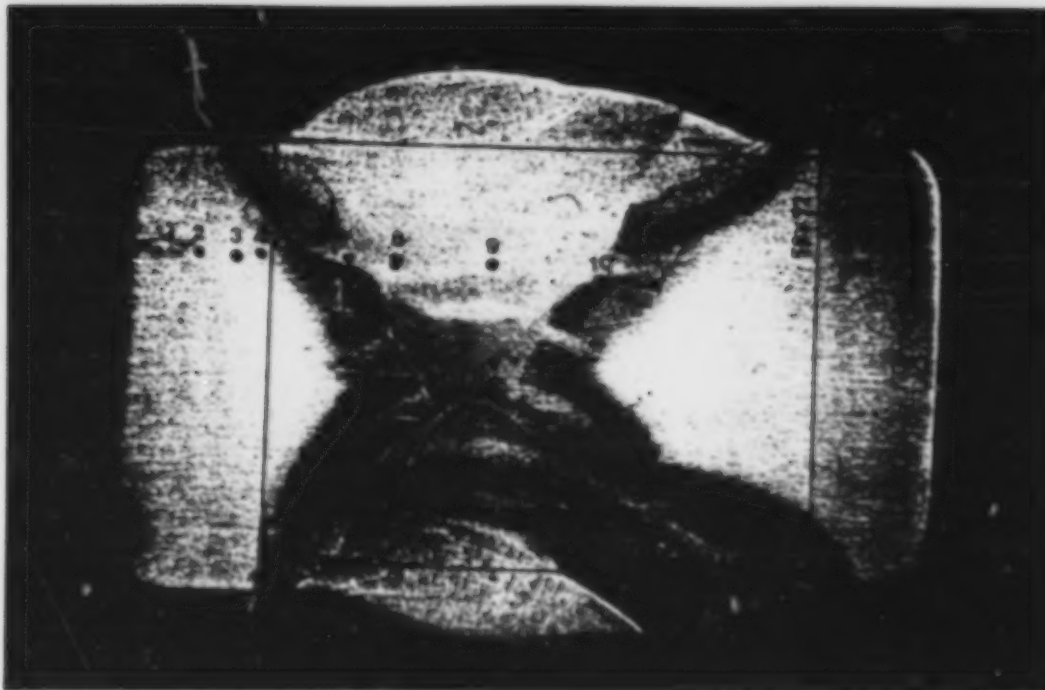


Figure A9. Weldment XLA-1.

Table A34. Microhardness Survey of Weldment XLA-1.

Location	HV ₁₀₀₀
1 - PM	194
2 - PM	193
3 - PM	198
4 - HAZ	200
5 - HAZ	195
6 - HAZ	225
7 - HAZ	254
8 - WM	223
9 - WM	216
10 - HAZ	243

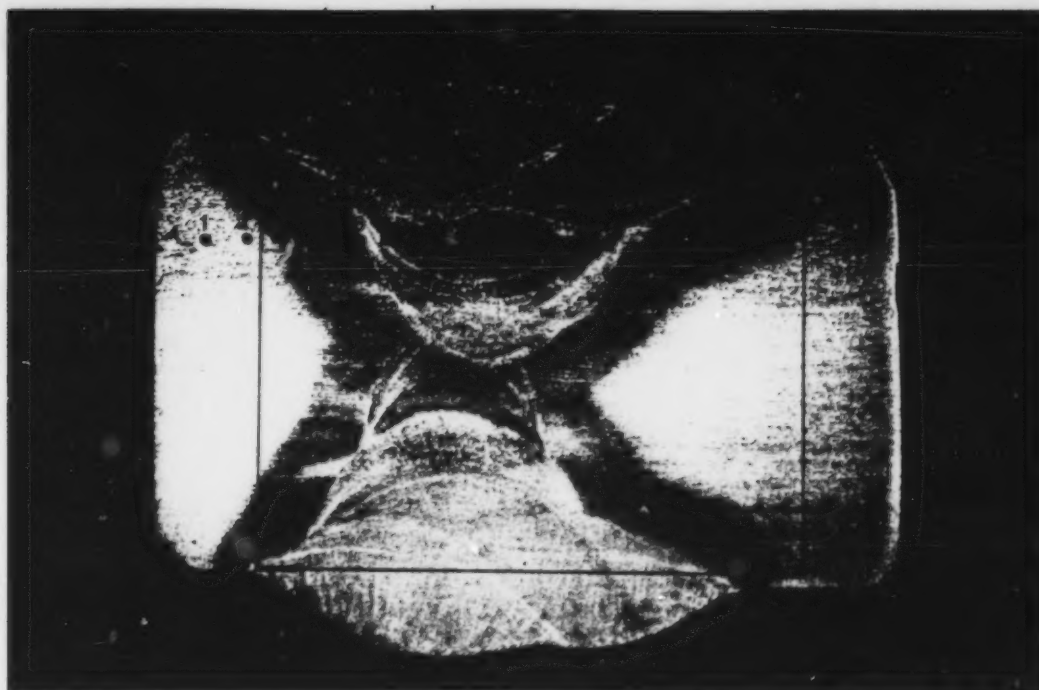


Figure A10. Weldment XLA-2.

Table A35. Microhardness Survey of Weldment XLA-2.

Location	HV ₁₀₀₀
1 - PM	190
2 - PM	194
3 - HAZ	196
4 - HAZ	206
5 - HAZ	235
6 - HAZ	230
7 - WM	242
8 - WM	229
9 - WM	223
10 - WM	227

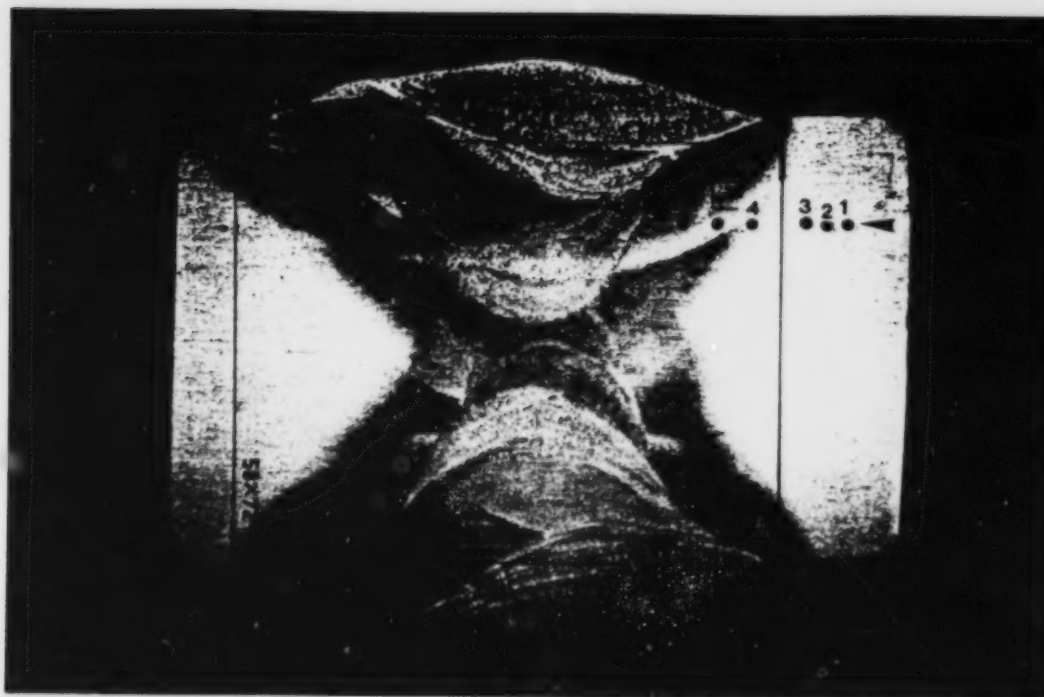


Figure A11. Weldment XLA-3.

Table A36. Microhardness Survey of Weldment XLA-3.

Location	HV ₁₀₀₀
1 - PM	209
2 - PM	208
3 - PM	210
4 - HAZ	203
5 - HAZ	214
6 - HAZ	233
7 - HAZ	243
8 - WM	233
9 - WM	227
10 - WM	216

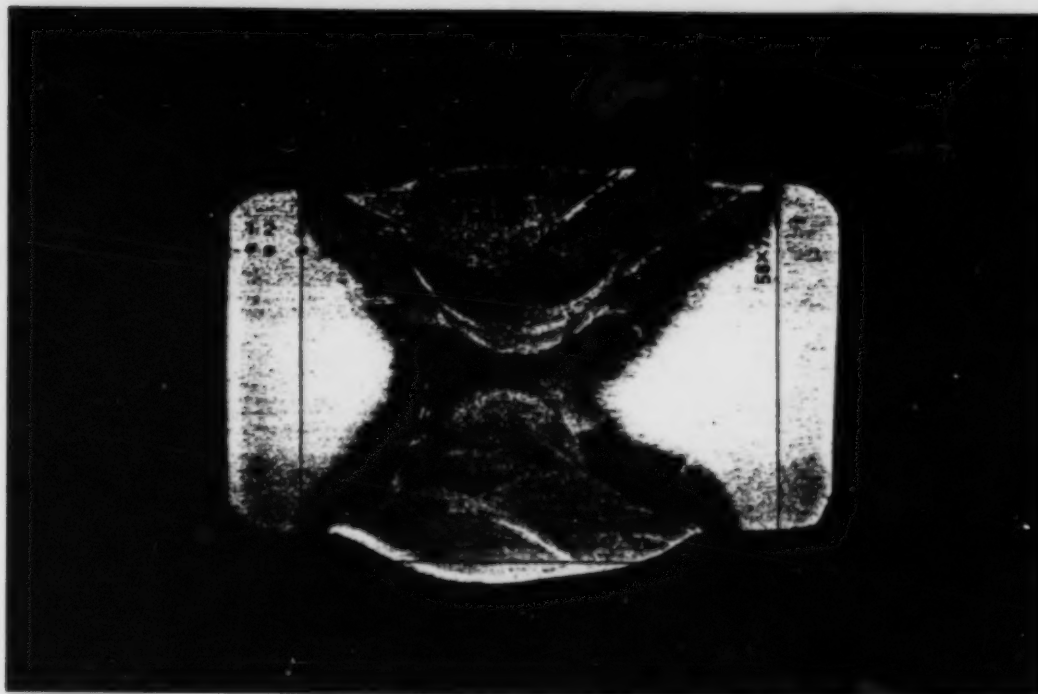


Figure A12. Weldment XLA-4.

Table A37. Microhardness Survey of Weldment XLA-4.

Location	HV ₁₀₀₀
1 - PM	192
2 - PM	196
3 - PM	202
4 - HAZ	209
5 - HAZ	221
6 - HAZ	224
7 - HAZ	265
8 - WM	237
9 - WM	241
10 - WM	237



Figure A13. Weldment XLS-1.

Table A38. Microhardness Survey of Weldment XLS-1.

Location	HV ₁₀₀₀
1 - PM	180
2 - PM	179
3 - PM	186
4 - PM	188
5 - HAZ	183
6 - HAZ	186
7 - HAZ	196
8 - HAZ	224
9 - HAZ	232
10 - WM	228
11 - WM	212
12 - WM	209



Figure A14. Weldment XLS-2.

Table A39. Microhardness Survey of Weldment XLS-2.

Location	HV ₁₀₀₀
1 - PM	188
2 - PM	188
3 - PM	192
4 - HAZ	190
5 - HAZ	200
6 - HAZ	208
7 - HAZ	211
8 - WM	223
9 - WM	224
10 - WM	220
11 - WM	213

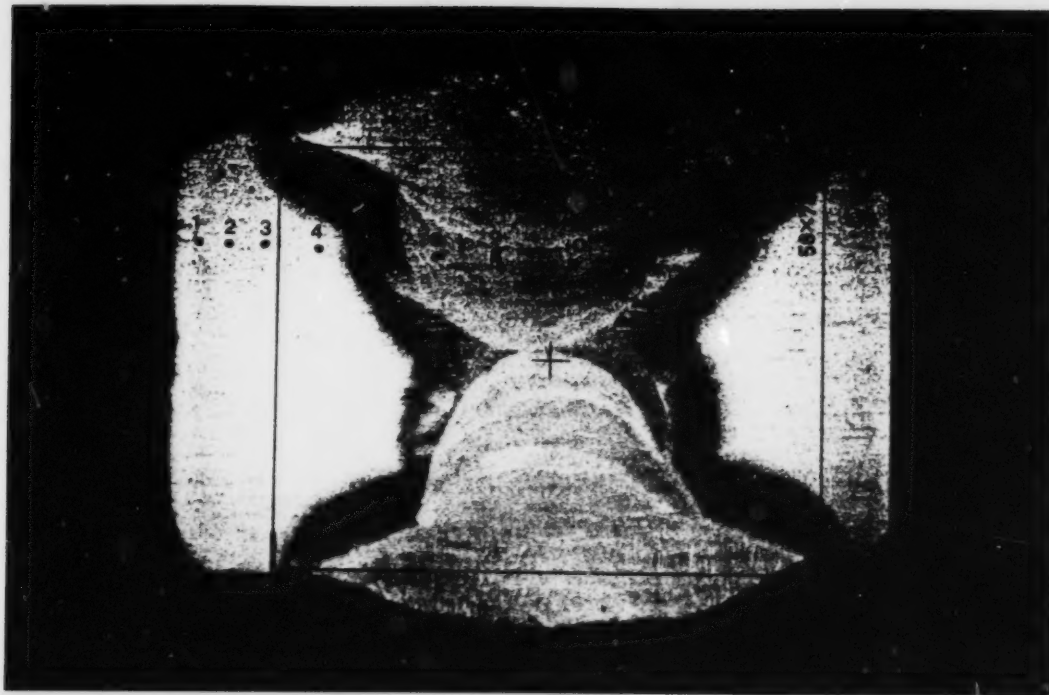


Figure A15. Weldment XLS-3.

Table A40. Microhardness Survey of Weldment XLS-3.

Location	HV ₁₀₀₀
1 - PM	184
2 - PM	192
3 - PM	192
4 - PM	192
5 - HAZ	194
6 - HAZ	196
7 - HAZ	236
8 - WM	215
9 - WM	220
10 - WM	229

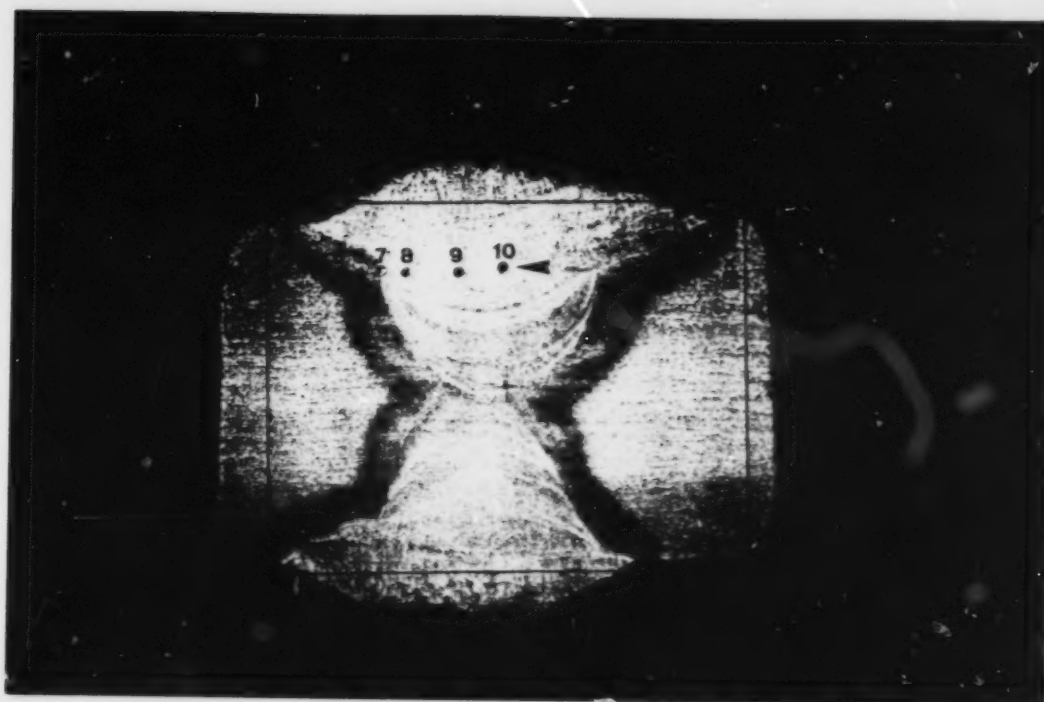


Figure A16. Weldment XLS-4.

Table A41. Microhardness Survey of Weldment XLS-4.

Location	HV ₁₀₀₀
1 - PM	180
2 - PM	188
3 - PM	203
4 - HAZ	208
5 - HAZ	215
6 - HAZ	246
7 - HAZ	261
8 - WM	220
9 - WM	208
10 - WM	214

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FAX 519-821-7700

The Galt Testing Laboratories Limited

ESTABLISHED 1989

Chemical Analysis of
Malleable, Meehanite, Ductile
and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slag, Etc.

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15 HIGHRIDGE COURT (AT PINEBUSH ROAD)
P.O. BOX 363
CAMBRIDGE (GALT), ONTARIO
N1R 7L3

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography;
Sand Testing;
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE A42

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1196

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 1/2" Thick

XHA-1

Specimen Dimensions	1.501 X 0.557	in.
Area of Cross Section	0.836	sq. in.
Maximum Load	74,500	lbf
Tensile Strength	89,000	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured in the
weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

This report relates only to the specimen or specimens tested and does not guarantee
the bulk material, etc., to be equal quality. The testing and inspection of instruments,
materials, and other articles is only undertaken by the Galt Testing Laboratories
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The Galt Testing Laboratories

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Pat Bill Bartlett Bill Bartlett
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Chemical Analysis of
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and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronzes;
Cast, Cast, Limestone,
Slags, Etc.

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N1R 7L3

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Tension, Hardness, Bend,
Notched Bar Impact,
Metallography:
Sand Testing:
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE A43

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1197

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 1/2" Thick

XHA-5

Specimen Dimensions	1.501 X 0.564	in.
Area of Cross Section	0.847	sq. in.
Maximum Load	75,600	lbf
Tensile Strength	89,500	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.
The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

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Chemical Analysis of
Metals, Mechanics, Ductile
and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slags, Etc.

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Notched Bar Impact,
Metallography,
Sand Testing,
Reports

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Oakville, Ontario
L6J 6C9

TABLE A44

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1192

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 1/2" Thick

XHS-1

Specimen Dimensions	1.500 X 0.550	in.
Area of Cross Section	0.825	sq. in.
Maximum Load	73,400	lbf
Tensile Strength	89,000	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

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Chemical Analysis of
Metals, Machine, Cast
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Alloys and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slag, etc.

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Tension, Hardness, Bend,
Notched Bar Impact,
Metallography;
Sand Testing;
Reports

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391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE A45

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1193

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 1/2" Thick

XHS-5

Specimen Dimensions	1.502 X 0.554	in.
Area of Cross Section	0.832	sq. in.
Maximum Load	72,800	lbf
Tensile Strength	87,500	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.
The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
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Chemical Analysis of
Malleable, Meehanite, Ductile
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Brass and Bronze;
Coal, Coke, Limestone,
Slags, Etc.

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Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography;
Sand Testing:
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE A46

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1198

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 1/2" Thick

XLA-1

Specimen Dimensions	1.501 X 0.548	in.
Area of Cross Section	0.823	sq. in.
Maximum Load	75,200	lbf
Tensile Strength	91,500	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

This report relates only to the specimen or specimens tested and does not guarantee
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Chemical Analysis of
Malleable, Mechanical, Ductile
and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronzes;
Coal, Coke, Limestone,
Slags, Etc.

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Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography,
Sand Testing:
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE A47
Customer P.O.: RD5733

Laboratory Sample I.D. #: A1199

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 1/2" Thick

XLA-5

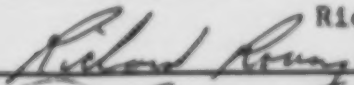
Specimen Dimensions	1.500 X 0.564	in.
Area of Cross Section	0.846	sq. in.
Maximum Load	76,200	lbf
Tensile Strength	90,000	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.
The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

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Chemical Analysis of
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and Cast Irons, Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slags, Etc.

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography,
Sand Testing,
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE A48

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1194

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 1/2" Thick

XLS-1

Specimen Dimensions	1.499 X 0.561	in.
Area of Cross Section	0.841	sq. in.
Maximum Load	75,400	lbf
Tensile Strength	89,500	psi

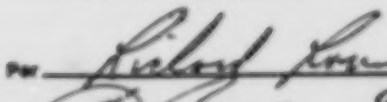
The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

This report relates only to the specimen or specimens tested and does not guarantee
the bulk material, etc., to be equal quality. The testing and inspection of instruments,
materials, and other articles is only undertaken by the Galt Testing Laboratories
Limited subject to the express stipulation that no liability or responsibility of any kind
or however arising shall attach to the Galt Testing Laboratories Limited, or any
employee of the Galt Testing Laboratories Limited, in respect of any loss, injury or
damage arising directly or indirectly out of, or in connection with any such inspection
or testing or any failure or omission in regard thereto.

The Galt Testing Laboratories

Per  Richard Rount
Technician
Per  Bill Bartlett
Senior Technician

TELEPHONE 519-621-5191
FAX 519-621-7700

Chemical Analysis of
Malleable, Mechanical, Ductile
and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slags, Etc.

The Galt Testing Laboratories Limited

CHEMISTS and METALLURGISTS

15 HIGHRIDGE COURT (AT PINEBUSH ROAD)

P.O. BOX 363

CAMBRIDGE (GALT), ONTARIO

N1R 7L3

ESTABLISHED 1929

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography;
Sand Testing;
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE A49

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1195

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 1/2" Thick

XLS-5

Specimen Dimensions	1.499 X 0.562	in.
Area of Cross Section	0.842	sq. in.
Maximum Load	74,300	lbf
Tensile Strength	88,000	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.
The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

This report relates only to the specimen or specimens tested and does not guarantee
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damage arising directly or indirectly out of, or in connection with any such inspection
or testing or any failure or omission in regard thereto.

The Galt Testing Laboratories

Per Richard Roun Richard Roun
Technician
Per Bill Bartlett Bill Bartlett
Senior Technician

Table A50

Bend Test Report

Client: Transport Canada
Client P.O. Number:
WIC Contract Number: RC343
Test Standard:

Specimen Standard: ANSI/AWS D1.1-88
Specimen Material: Steel X Weldment
9.5 x 14.3 mm size specimen

Specimen Number	Specimen Type	Defects	Result
XHA-1	side bend	NONE	pass
-2	side bend	NONE	pass
-3	side bend	NONE	pass
XHS-1	side bend	NONE	pass
-2	side bend	NONE	pass
-3	side bend	NONE	pass
XLA-1	side bend	NONE	pass
-2	side bend	two 0.2 mm pinhole defects	pass
-3	side bend	NONE	pass
XLS-1	side bend	NONE	pass
-2	side bend	2 mm long surface crack near the edge preparation.	pass
-3	side bend	1 mm long crack at the fusion boundary.	pass
XLA-4	side bend	NONE	pass
XLS-4	side bend	NONE	pass
XHA-4	side bend	NONE	pass
XHS-4	side bend	NONE	pass

Comments: 180 deg. side bend around 25.4mm radius.

Date: Nov./89

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A51

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: HAZ

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
XHA-1	-46		24		7	0.25
-2	-46		10		3	0.08
-3	-46		91		20*	1.25
-4	-46		26		7	0.31
-5	-46		58		10*	0.81
-6	-46		9		3	0.05
-7	-46		18		5	0.25
-8	-46		8		3	0.05
-9	-46		119		20	1.78
-10	-46		99		15	1.40
-11	-46		29		10	0.46
-12	-46		45		10	0.58
-13	-46		53		10	0.71
-14	-46		94		15	1.40
-15	-46		143		25	1.63
-16	-46		114		50	2.11

Comments: As-welded HAZ of sub-arc weldment. Date: Oct./89

* Shear area located at notch base.

Tested by: I.M.

Witnessed by:

Project Engineer: S.R.B.

Table A52

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: HAZ

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
XHS-1	-46		107		15*	1.09
-2	-46		13		3	0.13
-3	-46		30		7	0.36
-4	-46		38		7*	0.51
-5	-46		66		10*	0.97
-6	-46		27		15	0.46
-7	-46		17		3	0.23
-8	-46		19		7	0.25
-9	-46		13		8	0.25
-10	-46		56		8	0.76
-11	-46		18		8	0.31
-12	-46		117		20	1.68
-13	-46		41		10	0.61
-14	-46		48		10	0.69
-15	-46		30		8	0.33
-16	-46		21		15	0.43

Comments: Stress-relieved HAZ of sub-arc weldment.

Date: Oct./89

Tested by: I.M.

* Shear area concentrated in the zone below the notch tip.

Witnessed by:

Project Engineer: S.R.B.

Table A53

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: HAZ

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
XLA-1	-46		29		20	0.46
-2	-46		18		5	0.33
-3	-46		37		15	0.56
-4	-46		27		17	0.36
-5	-46		23		7	0.25
-6	-46		23		20	0.31
-7	-46		28		7	0.33
-8	-46		102		25*	1.27
-9	-46		63		30	0.84
-10	-46		55		25	0.84
-11	-46		42		35	0.58
-12	-46		65		25	0.89
-13	-46		32		25	0.51
-14	-46		59		35	0.86
-15	-46		78		40	1.04
-16	-46		25		25	0.43

Comments: As-welded HAZ of shielded metal arc weldment.

Date: Oct./89

Tested by: I.M.

Witnessed by:

Project Engineer: S.R.B.

* Shear area concentrated below the area of notch tip.

Table A54

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: HAZ

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
XLS-1	-46		27		20	0.41
-2	-46		22		20	0.28
-3	-46		98		30*	1.32
-4	-46		67		35*	0.94
-5	-46		23		10	0.23
-6	-46		31		15	0.46
-7	-46		27		7	0.43
-8	-46		23		5	0.46
-9	-46		40		25	0.56
-10	-46		59		25	0.81
-11	-46		25		20	0.30
-12	-46		69		35	0.86
-13	-46		46		30	0.66
-14	-46		44		40	0.61
-15	-46		28		35	0.41
-16	-46		39		20	0.53

Comments: Stress-relieved HAZ of shielded metal arc weldment.

Date: Oct./89

Tested by: I.M.

* Shear area concentrated in the area below the notch tip.

Witnessed by:

Project Engineer: S.R.B

Table A55

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: WM

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
XHA-1 -2	-46	WELD	11		4	0.05
	-46	WELD	13		4	0.05
-3	-46	WELD	10		4	0.03
-4	-46	WELD	9		4	0.03
-5	-46	WELD	8		4	-

Comments: As-welded sub arc weld metal.

Date: Oct./89

Tested by: I.M.

Witnessed by:

Project Engineer: S.R.B.

Table A56

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: WM

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
XHS-1 -2	-46 -46	WELD WELD	65 35		10 5	0.69 0.38
-3	-46	WELD	51		10	0.48
-4	-46	WELD	18		4	0.13
-5	-46	WELD	33		5	0.38

Comments: Stress-relieved
sub arc weld metal.

Date: Oct./89

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A57

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: WM

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
XLA-1 -2	-46	WM	58		35	0.76
	-46	WM	64		40	0.84
-3	-46	WM	68		45	0.86
-4	-46	WM	47		40	0.56
-5	-46	WM	90		55	1.09

Comments: As-welded shielded metal arc weld metal.

Date: Oct./89

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

Table A58

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: WM

WIC Contract Number: RC343

Specimen Material: Steel X

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
XLS-1 -2	-46	WELD	28		25	0.33
	-46	WELD	33		30	0.36
-3	-46	WELD	34		30	0.36
-4	-46	WELD	25		35	0.25
-5	-46	WELD	42		35	0.58

Comments: Stress-relieved shielded metal
arc weld metal.

Date: Oct./89

Tested by: M.I.

Witnessed by:

Project Engineer: S.R.B.

APPENDIX - B

TEST RESULTS FOR STEEL Y

- 1. Chemical Composition**
- 2. Base Plate Mechanical Tests**
- 3. Hot Forming Tests**
- 4. Cold Forming Tests**
- 5. Butt Weld Tests**



1. CHEMICAL COMPOSITION



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TECHNICAL SERVICES LTD.

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LABORATORY

2421 Drew Road, Mississauga, Ontario, Canada L5S 1A1
Tel. (416) 673-9899 Fax. (416) 673-8394

Customer: Welding Institute of Canada,
391 Burnhamthorpe Road, E.,
Oakville, Ontario.
L6J 6C9

Date: 30 August 1989.

Laboratory No. P-678

Attn: Dr. Sathish Rao Bala

Customer Order No. RD-5663

Laboratory Report

Client's Material

Description:

Item

Y1

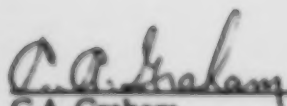
TABLE B1

Test Performed

Result

1. Chemical Analysis (% by weight)

Carbon	0.050
Manganese	1.57
Phosphorus	0.007
Sulphur	0.004
Silicon	0.35
Chromium	0.14
Nickel	0.02
Molybdenum	0.39
Copper	0.01
Vanadium	0.06
Niobium	0.052
Aluminum	0.042
Nitrogen	0.0065


C.A. Graham,
Chemical Analyst.


Anthony Araujo,
Laboratory Manager.

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Tel. (416) 673-9899 Fax. (416) 673-8394

Customer: Welding Institute of Canada,
391 Burnhamthorpe Road, E.,
Oakville, Ontario.
L6J 6C9

Date: 30 August 1989.

Laboratory No. P-679

Attn: Dr. Sathish Rao Bala

Customer Order No. RD-5663

Laboratory Report

Client's Material
Description:

Item Y26

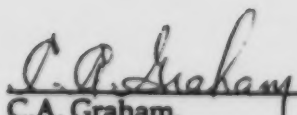
TABLE B2

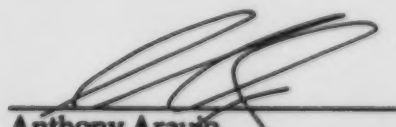
Test Performed

Result

1. Chemical Analysis (% by weight)

Carbon	0.045
Manganese	1.57
Phosphorus	0.007
Sulphur	0.004
Silicon	0.36
Chromium	0.14
Nickel	0.02
Molybdenum	0.37
Copper	0.01
Vanadium	0.06
Niobium	0.051
Aluminum	0.045
Nitrogen	0.0059


C.A. Graham,
Chemical Analyst.


Anthony Araujo,
Laboratory Manager.

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2. BASE PLATE MECHANICAL TESTS

Transverse Tensiles:

Y15AR = As-received
Y15SR = stress relieved

Longitudinal CVN:

Y16AR = As-received
Y17SR = stress relieved

Lateral CVN:

Y18A = As-received
Y18S = stress relieved

Table B3.

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel Y

Test Standard: A-370

(AR & SR)

Specimen Number	Y15AR-1	Y15AR-2	Y15SR-1	Y15SR-2
Initial Thickness or Diameter (mm)	8.920	8.923	8.923	8.905
Initial Width (mm)				
Initial Cross-sectional Area (mm ²)	62.52	62.52	62.52	62.26
Initial Gauge Length (mm)	35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)				
Final Width (mm)				
Final Cross-sectional Area (mm ²)				
Final Gauge Length (mm)	46.74	46.74	48.01	46.99
Yield or Offset* Load (kN) Upper 0.2%	28.25	28.25	32.87 31.12	32.87 30.88
Maximum Load (kN)	37.87	37.87	36.50	36.50
Yield Strength (MPa) Upper 0.2%	452	452	525 498	528 495
Ultimate Tensile Strength (MPa)	606	605	584	586
Elongation (%)	31.5	31.5	35	32
Reduction of Area (%)				
Failure Location				

Comments: Steel Y

Date: Aug./89

Lower YS (MPa)

Tested by: I.M.

Y15AR #1 = ---

Y15AR #2 = ---

Witnessed by:

Y15SR #1 = 490

Y15SR #2 = 490

Project Engineer: S.R.B.

Table B4

Charpy Impact Test Report

Client: Transport Canada / Procor

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

as-received (Y16 AR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y16A-1	23		322		100	NB
-2	0		316		100	1.68
-3	-50		259		100	2.31
-4	-80		179		60	2.11
-5	-110		97		30	1.37
-6	-110		19		15	0.20
-7	-110		89		30	1.25
-8	-130		6		2	0.03
-9	-130		6		2	0.03
-10	-130		8		2	0.03
-11	-120		11		2	0.03
-12	-120		52		20	0.71
-13	-120		11		4	0.05
-14	-95		135		30	1.73
-15	-95		121		25	1.65
-16	-95		130		25	1.75
-17	-15		279		100	2.34
-18	-30		242		100	2.29
-19	0		318		100	NB
-20	-30		265		100	2.36

Comments: Steel Y, as-received
Longitudinal

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B5

Charpy Impact Test Report

Client: Transport Canada / Procor

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: Stress relieved

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

(Y17 SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y17SR-1	23		320		100	NB
-2	-80		223		100	2.44
-3	-80		152		60	1.58
-4	-80		166		60	2.03
-5	-100		122		40	1.37
-6	-100		152		50	1.91
-7	-120		5		2	0
-8	-120		6		3	0
-9	-135		5		2	0
-10	-110		155		50	1.96
-11	-110		112		30	1.60
-12	-115		12		5	0.08
-13	-110		107		30	1.50
-14	0		270		100	1.60
-15	-20		234		100	1.83
-16	-20		315		100	NB
-17	-40		253		100	1.85
-18	-40		322		100	NB
-19	-60		230		80	2.41
-20	-60		248		80	1.93

Comments: Steel Y
Stress Relieved

Longitudinal

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B6

Charpy Impact Test Report

Client: Transport Canada / Procor

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

(Y18 AR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y18AR-1	23		190		100	2.16
-2	-50		128		60	1.75
-3	-80		92		45	1.17
-4	-110		13		10	0.10
-5	-130		7		4	0.03
-6	-120		11		5	0.05
-7	-95		60		40	0.74
-8	0		200		100	1.80
-9	-15		218		100	2.24
-10	-30		167		90	0.20

Comments: Steel Y
Transverse Specimens
as-received

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B7

Charpy Impact Test Report

Client: Transport Canada / Procor

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Stress-relieved (Y18 SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y18SR-1	23		232		100	1.75
-2	-80		142		60	1.55
-3	-100		20		25	0.25
-4	-120		10		15	0.08
-5	-135		5		3	0
-6	-90		100		40	1.14
-7	0		270		100	2.16
-8	-20		282		100	2.18
-9	-40		170		70	1.60
-10	-60		148		60	1.85

Comments: Steel Y
Stress-relieved
Transverse

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

3. HOT FORMING TESTS

Transverse Tensiles and Longitudinal CVN:

Y19 = 566° C + stress relieve
Y20 = 593° C + stress relieve
Y21 = 621° C + stress relieve
Y22 = 649° C + stress relieve
Y23 = 677° C + stress relieve
Y24 = 760° C + stress relieve
Y25 = 899° C + stress relieve

Table B8

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel Y

Test Standard: A-370

Y19(566°C, SR), Y20(593°C, SR)

Specimen Number		Y19-1	Y19-2	Y20-1	Y20-2
Initial Thickness or Diameter (mm)		8.89	8.65	8.89	8.28
Initial Width (mm)					
Initial Cross-sectional Area (mm ²)		62.06	58.71	62.06	53.87
Initial Gauge Length (mm)		35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)					
Final Width (mm)					
Final Cross-sectional Area (mm ²)					
Final Gauge Length (mm)		47.50	46.74	47.24	47.75
Yield or Offset ¹ Load (kN)	Upper	32.25	30.37	32.25	29.00
	0.2%	31.00	29.00	30.50	27.00
Maximum Load (kN)		36.50	34.50	36.00	31.50
Yield Strength (MPa)	Upper	514	517	520	539
	0.2%	499	494	492	501
Ultimate Tensile Strength (MPa)		588	588	580	585
Elongation (%)		33.5	31.5	33	34.5
Reduction of Area (%)					
Failure Location					

Comments: Steel Y, hot formed

Date: Aug./89

Lower YS (MPa)

Y19-1 = 491

Tested by: I.M.

Y19-2 = 492

Y20-1 = 477

Witnessed by:

Y20-2 = 488

Project Engineer: S.R.B.

Table B9

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel Y

Test Standard: A-370

Y22 (649°C, SR), Y23 (677°C, SR)

Specimen Number		Y22-1	Y22-2	Y23-1	Y23-2
Initial Thickness or Diameter (mm)		8.85	8.87	8.91	8.93
Initial Width (mm)					
Initial Cross-sectional Area (mm ²)		61.48	61.81	62.39	62.58
Initial Gauge Length (mm)		35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)					
Final Width (mm)					
Final Cross-sectional Area (mm ²)					
Final Gauge Length (mm)		46.99	46.99	46.99	46.99
Yield or Offset* Load (kN)	Upper	33.30	32.82	34.95	35.52
	0.2%	31.30	31.50	32.75	32.55
Maximum Load (kN)		36.37	36.62	37.05	37.05
Yield Strength (MPa)	Upper	542	531	561	568
	0.2%	509	510	525	520
Ultimate Tensile Strength (MPa)		592	593	594	592
Elongation (%)		32.1	32.1	32.1	32.1
Reduction of Area (%)					
Failure Location					

Comments: Steel Y, hot formed

Date: Aug./89

Lower YS (MPa)

Tested by: J.M.I.

Y22-1 = 504

Y22-2 = 502

Witnessed by:

Y23-1 = 521

Y23-2 = 517

Project Engineer: S.R.B.

Table B10

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel Y

Test Standard: A-370

Y21 (621°C, SR); Y25 (899°C, SR)

Specimen Number		Y21-1	Y21-2	Y25-1	Y25-2
Initial Thickness or Diameter (mm)		8.90	8.882	8.905	8.882
Initial Width (mm)					
Initial Cross-sectional Area (mm ²)		62.32	61.94	62.26	61.94
Initial Gauge Length (mm)		35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)					
Final Width (mm)					
Final Cross-sectional Area (mm ²)					
Final Gauge Length (mm)		47.24	47.24	47.50	47.75
Yield or Offset* Load (kN)	Upper	33.49	32.50	29.00	27.50
	0.2%	30.63	31.00	28.50	27.00
Maximum Load (kN)		36.50	36.25	37.00	36.37
Yield Strength (MPa)	Upper	538	525	465	444
	0.2%	492	501	458	436
Ultimate Tensile Strength (MPa)		585	585	594	587
Elongation (%)		33	33	33.5	34.5
Reduction of Area (%)					
Failure Location					

Comments: Steel Y, hot formed

Date: Aug./89

Lower YS (MPa)

Tested by: I.M.

Y21-1 = 489

Y21-2 = 484

Witnessed by:

Y25-1 = 453

Y25-2 = 432

Project Engineer: S.R.B.

Table B11

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel Y

Test Standard: A-370

Y24 (760°C, SR)

Specimen Number	Y24-1	Y24-2		
Initial Thickness or Diameter (mm)	8.92	8.93		
Initial Width (mm)				
Initial Cross-sectional Area (mm ²)	62.52	62.65		
Initial Gauge Length (mm)	35.56	35.56		
Final Thickness or Diameter (mm)				
Final Width (mm)				
Final Cross-sectional Area (mm ²)				
Final Gauge Length (mm)	47.75	46.48		
Yield or Offset* Load (kN)	Upper 0.2%	28.25 27.25	---- 22.87	
Maximum Load (kN)		35.25	36.82	
Yield Strength (MPa)	Upper 0.2%	452 436	---- 365	
Ultimate Tensile Strength (MPa)		564	588	
Elongation (%)		34.3	30.7	
Reduction of Area (%)				
Failure Location				

Comments: Steel Y, hot formed
Lower YS (MPa)
Y24-1 = 426
Y24-2 = 355

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B12

Charpy Impact Test Report

Client: Transport Canada / Procor

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

566 deg. C, SR (Y19)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y19-1 -2	-46 -46		237 198		90 85	2.39 2.18
-3	-46		224		85	2.41
-3	-46		298		100	1.65
-4	-46		208		80	2.29

Comments: Steel Y

Date: Aug./89

Hot Formed

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B13

Charpy Impact Test Report

Client: Transport Canada / Procor

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

593 deg. C, SR (Y20)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y20-1 -2	-46 -46		205 223		85 85	2.26 2.24
-3	-46		205		85	2.26
-4	-46		250		90	1.75
-5	-46		272		98	2.44

Comments: Steel Y

Hot Formed

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B14 Charpy Impact Test Report

Client: Transport Canada

Client P.O. Number:

WIC Contract Number: RC343

Test Standard: ASTM E23

Specimen Standard: ASTM E23

Specimen Type:

Specimen Material: A 8XX Gr. B

Steel Y 621 deg. C, SR (Y21)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y21-1 -2	-46 -46		235 315		85 100	2.34 1.70
-3	-46		317		100	NB
-4	-46		284		95	1.75
-5	-46		222		85	2.39

Comments: Steel Y, hot formed

Date: Aug/89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B15

Charpy Impact Test Report

Client: Transport Canada / Procor

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

649 deg. C, SR (Y22)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y22-1 -2	-46 -46		315 268		100 95	NB 1.75
-3	-46		247		90	2.44
-4	-46		216		80	1.80
-5	-46		317		100	NB

Comments: Steel Y

Date: Aug./89

Hot Formed

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B16

Charpy Impact Test Report

Client: Transport Canada / Procor

Client P.O. Number:

WIC Contract Number: RC343

Test Standard: ASTM E23

Specimen Standard: ASTM E23

Specimen Type:

Specimen Material: Steel Y

677 deg. C, SR (Y23)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y23-1 -2	-46 -46		283 317		98 100	2.20 NB
-3	-46		296		98	2.34
-4	-46		291		100	1.68
-5	-46		315		100	NB

Comments: Steel Y

Hot Formed

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B17

Charpy Impact Test Report

Client: Transport Canada / Procor

Client P.O. Number:

WIC Contract Number: RC343

Test Standard: ASTM E23

Specimen Standard: ASTM E23

Specimen Type:

Specimen Material: Steel Y

760 deg. C, SR (Y24)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y24-1 -2	-46 -46		317 320		100 100	NB NB
-3	-46		317		100	NB
-4	-46		317		100	NB
-5	-46		318		100	NB

Comments: Steel Y

Hot Formed

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B18

Charpy Impact Test Report

Client: Transport Canada / Procor

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

899 deg. C, SR (Y25)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y25-1 -2	-46 -46		318 318		100 100	NB NB
-3	-46		318		100	NB
-4	-46		324.5		100	NB
-5	-46		319		100	NB

Comments: Steel Y
Hot Formed

Date: Aug./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

4. COLD FORMING TESTS

Transverse Tensiles and Longitudinal CVN:

Y6, Y7 = 5% cold formed (as-formed)

Y8, Y9 = 5% cold formed + stress relieved

Y10, Y11 = 10% cold formed (as-formed)

Y12, Y13 = 10% cold formed + stress relieved

Table B19

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC-343

Specimen Material: Steel Y

Test Standard: A-370

Y6, Y7 (5% cold formed, as-formed)

Y10, Y11 (10% cold formed, as-formed)

Specimen Number	Y6AR-1	Y7AR-2	Y10AR-1	Y11AR-2	
Initial Thickness or Diameter (mm)	8.93	8.90	8.88	8.93	
Initial Width (mm)					
Initial Cross-sectional Area (mm ²)	62.65	62.13	61.96	62.58	
Initial Gauge Length (mm)	35.56	35.56	35.56	35.56	
Final Thickness or Diameter (mm)					
Final Width (mm)					
Final Cross-sectional Area (mm ²)					
Final Gauge Length (mm)	44.45	44.20	41.40	41.66	
Yield or Offset* Load (kN)	Upper	40.95	40.80	44.95	45.00
	Lower	40.12	40.12	44.00	43.75
Maximum Load (kN)	41.30	41.00	44.96	41.66	
Yield Strength (MPa)	Upper	654	656	725	717
	Lower	640	646	710	699
Ultimate Tensile Strength (MPa) 659	659	725	717		
Elongation (%)	25	24	16	17	
Reduction of Area (%)					
Failure Location					

Comments: Steel Y

0.2% offset YS

Y6AR-1 = 645 MPa

Y7AR-2 = 650 MPa

Y10AR-1 = 718 MPa

Y11AR-2 = 710 MPa

Date: Nov./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B20

Tensile Test Report

Client: Transport Canada

Specimen Standard:

Client P.O. Number:

Specimen Type: Stress relieved

WIC Contract Number: RC-343

Specimen Material: Steel Y

Test Standard: A-370

Y8, Y9 (5% cold formed, SR)

Y12, Y13 (10% cold formed, SR)

Specimen Number	Y8SR-1	Y9SR-2	Y12SR-1	Y13SR-2
Initial Thickness or Diameter (mm)	8.82	8.90	8.92	8.90
Initial Width (mm)				
Initial Cross-sectional Area (mm ²)	61.16	62.19	62.45	62.19
Initial Gauge Length (mm)	35.56	35.56	35.56	35.56
Final Thickness or Diameter (mm)				
Final Width (mm)				
Final Cross-sectional Area (mm ²)				
Final Gauge Length (mm)	46.23	45.72	45.21	44.45
Yield or Offset* Load (kN)	Upper	39.50	42.07	45.45
	Lower	37.62	39.22	42.25
Maximum Load (kN)	40.63	42.10	45.12	44.75
Yield Strength (MPa)	Upper	645	676	731
	Lower	615	631	677
Ultimate Tensile Strength (MPa)	664	677	724	671
Elongation (%)	30	29	27	25
Reduction of Area (%)				
Failure Location				

Comments: Steel Y

0.2% offset YS

Y8SR-1 = 625 MPa

Y9SR-2 = 633 MPa

Y12SR-1 = 685 MPa

Y13SR-2 = 679 MPa

Date: Nov./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B21

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Y6, Y7 (AR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y6-1	-46		246		100	NB
-2	-46		272		100	NB
-3	-80		29		20	0.33
-4	-80		29		25	0.28
-5	-80		26		25	0.30
-6	-100		12		5	0.05
-7	-100		14		5	0.03
-8	-100		13		5	0.13
-9	-120		6		0	0
-10	-120		8		0	0
Y7-11	-65		325+		100	NB
-12	-65		28		20	0.41
-13	-65		71		40	0.71
-14	-46		114		75	1.58
-15	-20		270		100	NB
-16	-20		280		100	NB
-17	-20		295		100	NB
-18	0		325+		100	NB
-19	0		272		100	1.85
-20	25 (RT)		235		100	2.51

Comments: Steel Y

Date: Nov./89

Cold-formed

Tested by: J.M.I.

Longitudinal

Witnessed by:

Project Engineer: S.R.B.

Table B22

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Y8, Y9 (SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y8-1	-46		325+		100	NB
-2	-46		262		100	NB
-3	-80		288		100	NB
-4	-80		54		30	0.64
-5	-80		75		50	1.91
-6	-100		15		5	0.05
-7	-100		12		5	0.13
-8	-100		10		3	0.03
-9	-120		6		0	0.03
-10	-120		6		0	0.00
Y9-11	-90		30		20	0.20
-12	-90		103		50	0.99
-13	-90		317		100	NB
-14	-65		280		100	NB
-15	-65		316		100	1.37
-16	-65		245		100	NB
-17	-46		255		100	NB
-18	-20		325+		100	NB
-19	-20		270		100	NB
-20	25 (RT)		325+		100	NB

Comments: Steel Y
Longitudinal
Cold formed + stress relieved

Date: Nov./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B23

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Y10, Y11 (AR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y10-1	-46		266		100	NB
-2	-46		257		100	NB
-3	-80		15		15	0.08
-4	-80		14		15	0.08
-5	-80		15		15	0.08
-6	-100		10		3	0
-7	-100		8		3	0.08
-8	-100		8		3	0
-9	-120		6		0	0
-10	-120		6		0	0
Y11-11	-65		290		100	NB
-12	-65		54		40	0.58
-13	-65		63		45	0.58
-14	-46		246		100	NB
-15	-20		263		100	NB
-16	-20		260		100	NB
-17	-20		278		100	NB
-18	0		265		100	1.30
-19	0		160		100	1.17
-20	25 (RT)		225		100	1.25

Comments: Steel Y, cold formed
Longitudinal

Date: Nov./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B24

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type:

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Y12, Y13 (SR)

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
Y12SR-1	-46		319		100	1.37
-2	-46		262		100	NB
-3	-80		17		15	0.08
-4	-80		33		20	0.18
-5	-80		325		100	NB
-6	-100		6		5	0
-7	-100		10		5	0.05
-8	-100		6		5	0
-9	-120		6		0	0
-10	-120		4		0	0
Y13-11	-90		325+		100	NB
-12	-90		23		25	0.18
-13	-90		12		5	0.05
-14	-65		325+		100	NB
-15	-65		294		100	NB
-16	-65		325+		100	NB
-17	-46		184		100	NB
-18	-20		288		100	NB
-19	-20		303		100	NB
-20	25 (RT)		292		100	NB

Comments: Cold formed & Stress relieved
longitudinal

Date: Nov./89

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.



5. BUTT WELD TESTS

Hardness Profiles, Bend Tests, Reduced Section Tensiles, HAZ CVN and Weld Metal CVN:

YHA = High heat input, as-welded

YHS = High heat input, stress relieved

YLA = Low heat input, as-welded

YLS = low heat input, stress relieved

WELDING DATA SHEET

WELDING INSTITUTE OF CANADA
INSTITUT DE SOUDAGE DU CANADA

CONTRACT NO. RC 343

DATA SHEET NO. 3

PROCESS: SMAW

MATERIALS: STEEL Y

POSITION: Flat (1G)

PREHEAT:

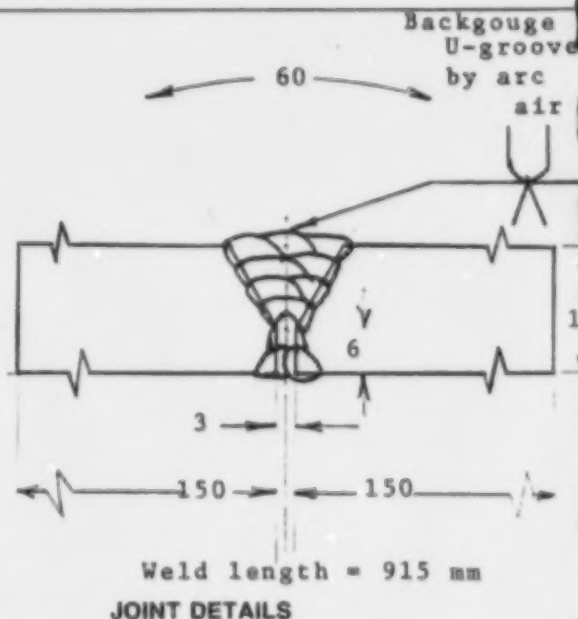
Preheat Temp. 120 deg.C (250 deg.F)
Interpass Temp. 150 deg.C (300 deg.F)
Preheat Maintenance

FILLER METAL:

Classification 55018-C1 (8018-C1)
Trade Name Atom Arc 8018-C1

FLUX:

Class:
Trade Name:



GAS COMPOSITION REQUIRED:

Shielding Gas At CFH
Backing Gas At CFH
Trailing Gas At CFH

ELECTRICAL CHARACTERISTICS:

Power Source: Lincoln DCRP 500
Current Type: DC
Polarity: RP

SPECIAL NOTES

Reverse side backgouged
Weld ID

YLA - Procor T 8917 = as-welded
YLS - Procor T 8918 = stress relieved

T	WELD SEQUENCE			ELECTRODE		WELDING VARIABLES					
	SIDE	LAYER	PASS	TYPE	SIZE mm	AMPS	VOLTS	E.S.O.	SPEED mmps	WFS lpm	HEAT INPUT
Backgouged	1	1	1		3	120/130	24		2		1.4 kJ/mm
	1	2	2-3		4	140	24		2		"
	1	3	4-5		4.8	200	26		2		"
	1	4	6-8		4.8	200	26		2		"
	2	1	9		4.8	200	26		2		"
	2	2	10-11		4.8	190	26		2		"
ISSUED BY:				DATE:		LAB TECHNOLOGIST:					

WELDING DATA SHEET

WELDING INSTITUTE OF CANADA
INSTITUT DE SOUDAGE DU CANADA



CONTRACT NO. RC 343

DATA SHEET NO. 4

PROCESS: SAW - Twin wire

MATERIALS: STEEL Y

POSITION: Flat (1G)

PREHEAT:

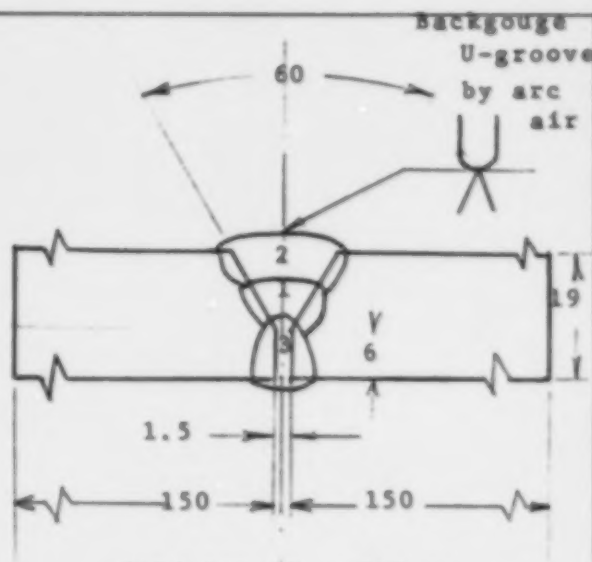
Preheat Temp. 150 deg.C (300 deg.F)
Interpass Temp. 205 deg.C (400 deg.F)
Preheat Maintenance

FILLER METAL:

Classification
Trade Name Lincoln L56 Wire

FLUX:

Class:
Trade Name: Lincoln 880M



Weld length = 915 mm

JOINT DETAILS

GAS COMPOSITION REQUIRED:

Shielding Gas	Ar	CFH
Backing Gas	Ar	CFH
Trailing Gas	Ar	CFH

ELECTRICAL CHARACTERISTICS:

Power Source: Lincoln DCRP1000
Current Type: DC
Polarity: RP

SPECIAL NOTES

Reverse side backgouged

Weld ID

YHA - Procor T 8919 = as-welded

YHS - Procor T 8920 = stress relieved

T	WELD SEQUENCE			ELECTRODE		WELDING VARIABLES					
	SIDE	LAYER	PASS	TYPE	SIZE mm	AMPS	VOLTS	E.S.O. mm	SPEED mmps	WFS lpm	HEAT INPUT
	1	1	1	L56	2.4/	850	30	32	9.3	69.4	2.7 kJ/mm
	1	2	2	..	2.4	850	30	..	6.8	69.4	3.8 kJ/mm
	Backgouged										
	2	1	3	..	..	850	30	..	6.8	69.4	3.8 kJ/mm
ISSUED BY:				DATE:		LAB TECHNOLOGIST:					

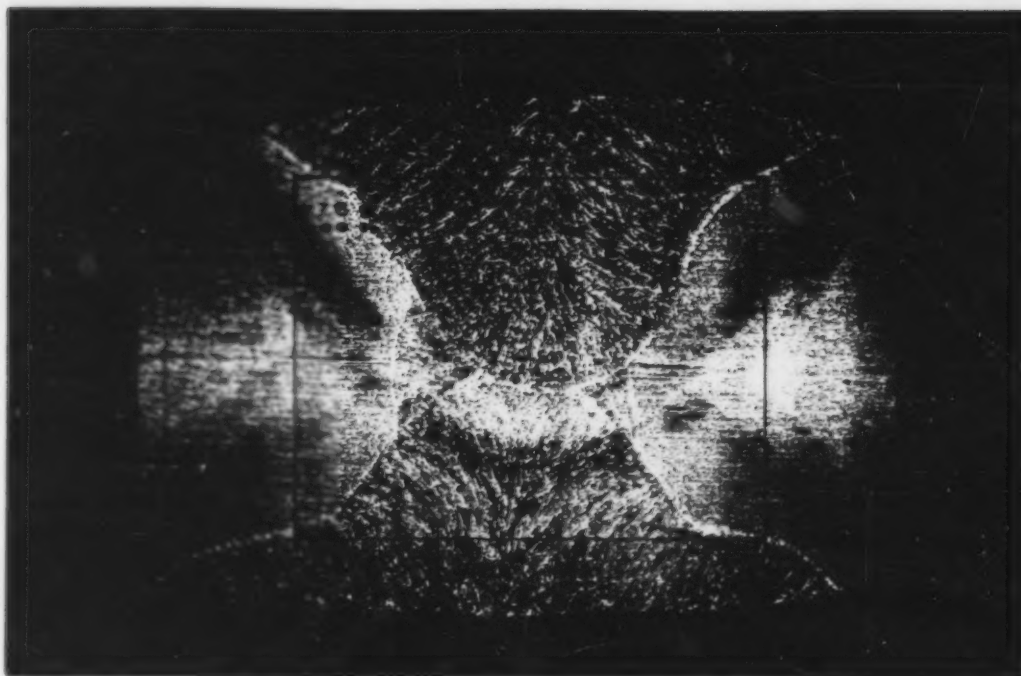


Figure B1. Weldment YHA-1.

Table B25. Microhardness Survey of Weldment YHA-1.

Location	HV ₁₀₀₀
1 - PM	196
2 - PM	201
3 - PM	206
4 - HAZ	200
5 - HAZ	204
6 - HAZ	214
7 - HAZ	223
8 - HAZ	227
9 - HAZ	226
10 - WM	224
11 - WM	233
12 - WM	232

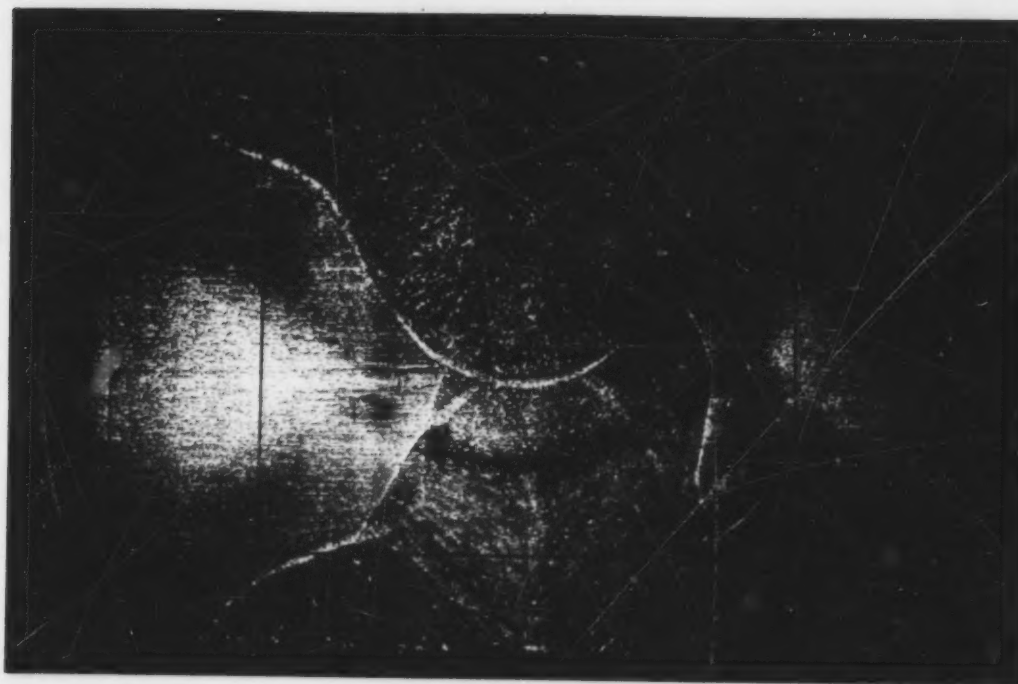


Figure B2. Weldment YHA-2.

Table B26. Microhardness Survey of Weldment YHA-2.

Location	HV ₁₀₀₀
1 - PM	195
2 - PM	203
3 - PM	201
4 - HAZ	206
5 - HAZ	196
6 - HAZ	208
7 - HAZ	211
8 - HAZ	220
9 - HAZ	226
10 - HAZ	223
11 - WM	218
12 - WM	220
13 - WM	223

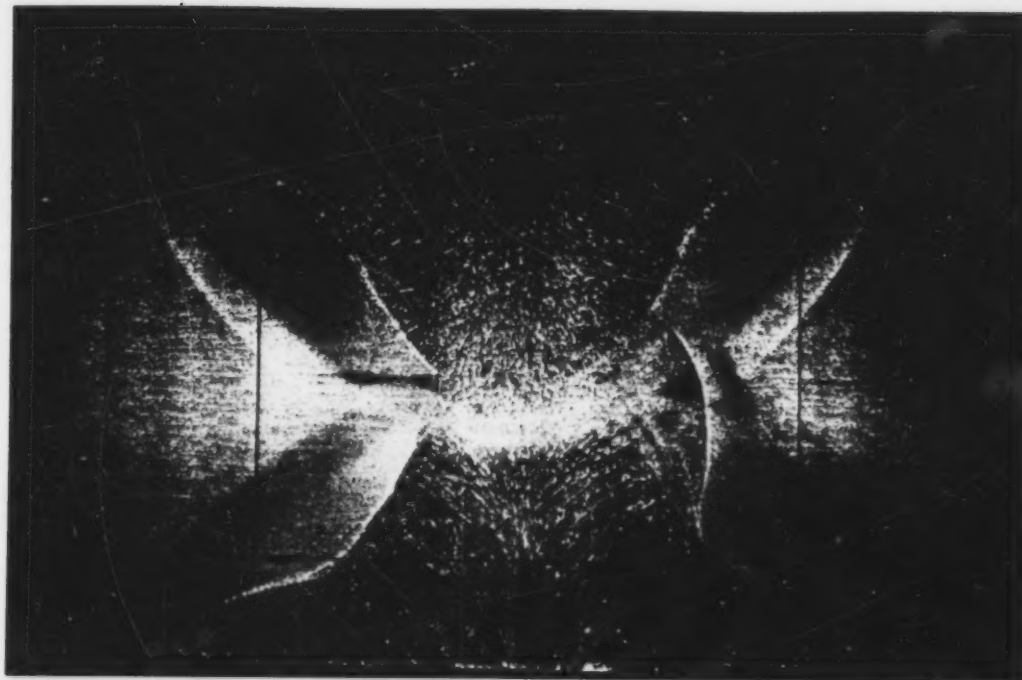


Figure B3. Weldment YHA-3.

Table B27. Microhardness Survey of Weldment YHA-3.

Location	HV ₁₀₀₀
1 - PM	206
2 - PM	207
3 - PM	208
4 - HAZ	211
5 - HAZ	210
6 - HAZ	225
7 - HAZ	227
8 - HAZ	228
9 - HAZ	238
10 - WM	230
11 - WM	228
12 - WM	223

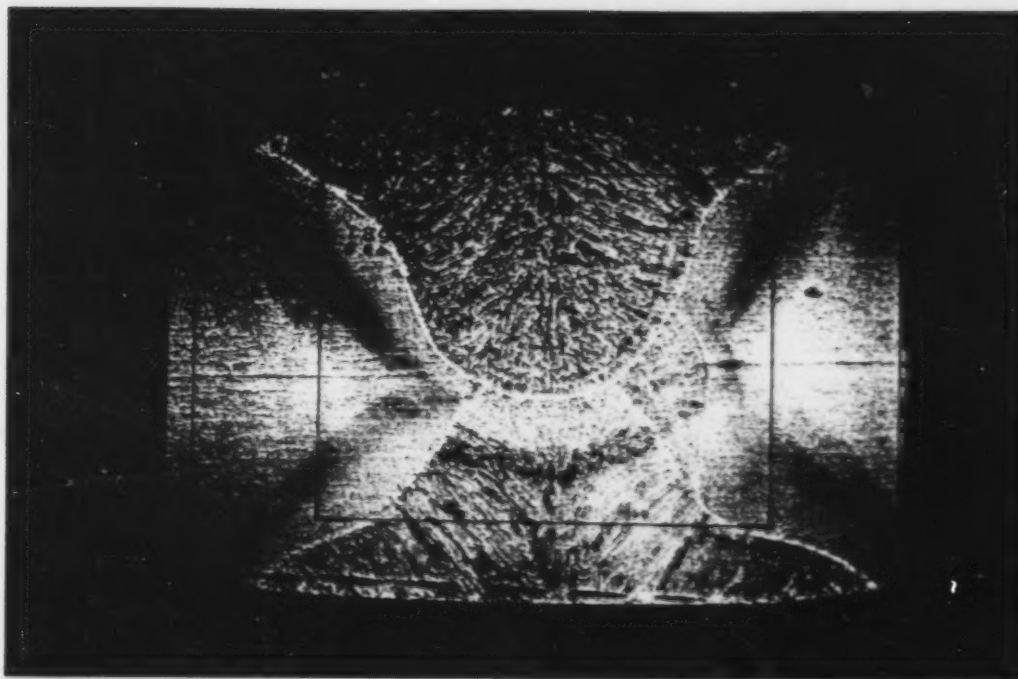


Figure B4. Weldment YHA-4.

Table B28. Microhardness Survey of Weldment YHA-4.

Location	HV ₁₀₀₀
1 - PM	205
2 - PM	211
3 - PM	207
4 - HAZ	210
5 - HAZ	215
6 - HAZ	225
7 - HAZ	226
8 - HAZ	226
9 - HAZ	237
10 - WM	233
11 - WM	236
12 - WM	232

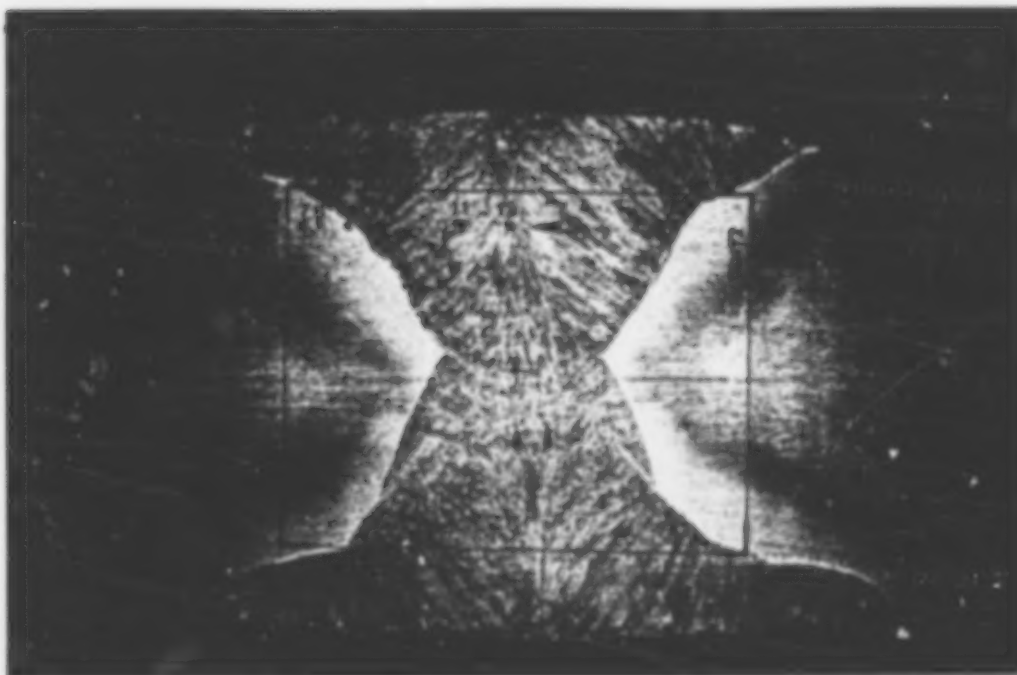


Figure B5. Weldment YHS-1.

Table B29. Microhardness Survey of Weldment YHS-1.

Location	HV _{0.05}
1 - PM	200
2 - PM	205
3 - PM	205
4 - HAZ	194
5 - HAZ	216
6 - HAZ	244
7 - HAZ	261
8 - HAZ	261
9 - HAZ	296
10 - WM	253
11 - WM	253
12 - WM	250

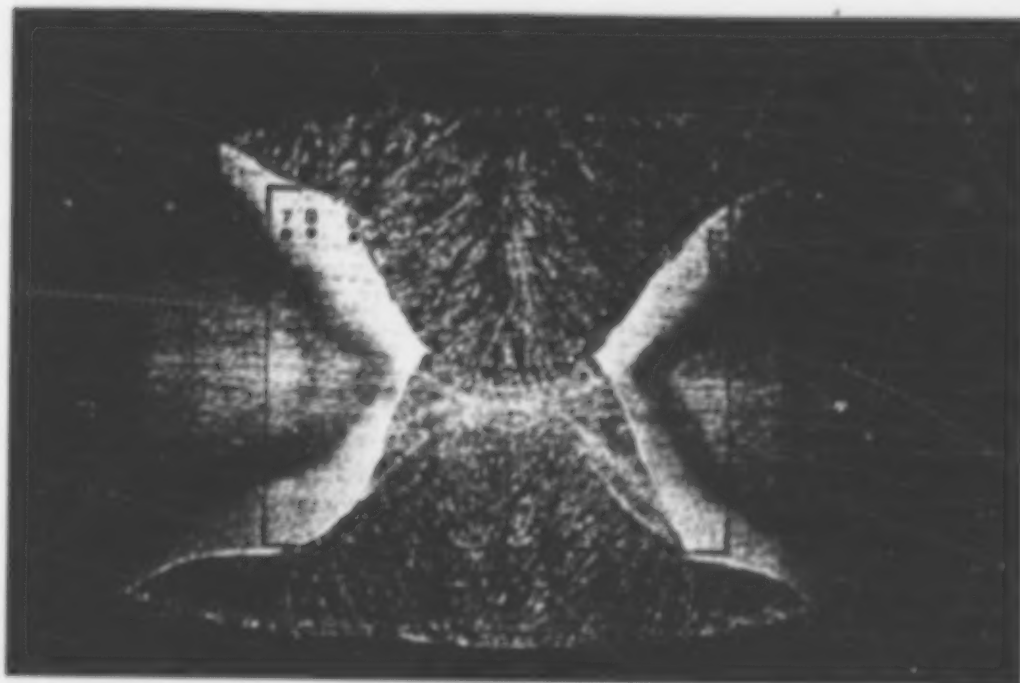


Figure B6. Weldment YHS-2.

Table B30. Microhardness Survey of Weldment YHS-2.

Location	HV _{0.05}
1 - PM	202
2 - PM	202
3 - PM	202
4 - PM	202
5 - HAZ	196
6 - HAZ	220
7 - HAZ	248
8 - HAZ	243
9 - HAZ	279
10 - WM	250
11 - WM	238
12 - WM	246

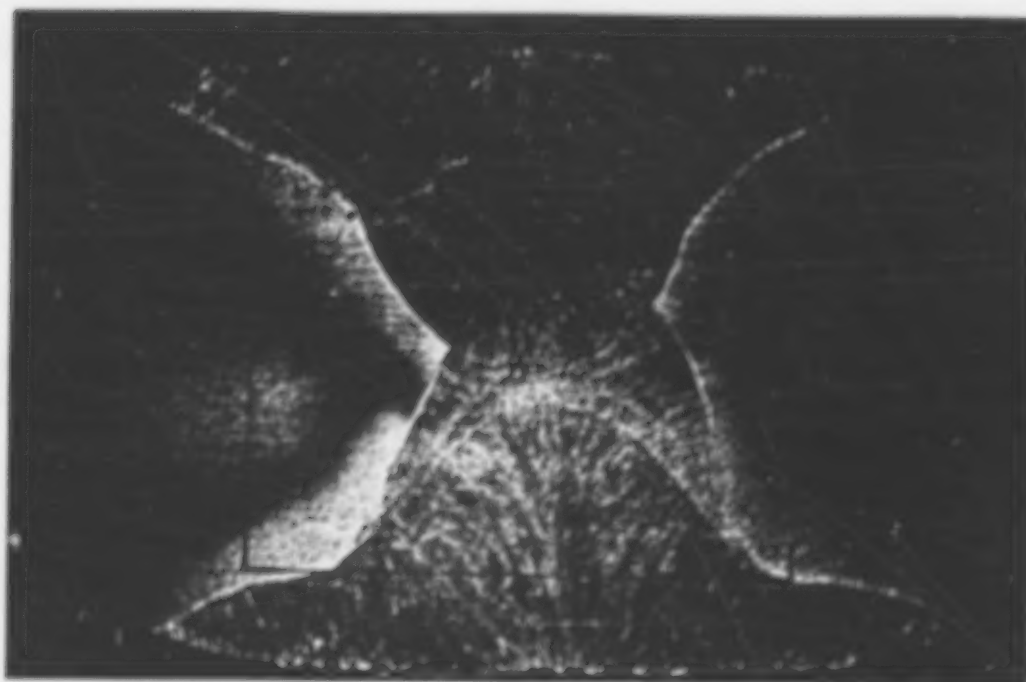


Figure B7. Weldment YHS-3.

Table B31. Microhardness Survey of Weldment YHS-3.

Location	HV _{0.05}
1 - PM	193
2 - PM	190
3 - PM	201
4 - PM	195
5 - HAZ	210
6 - HAZ	220
7 - HAZ	230
8 - HAZ	242
9 - HAZ	239
10 - HAZ	268
11 - WM	240
12 - WM	247
13 - WM	241

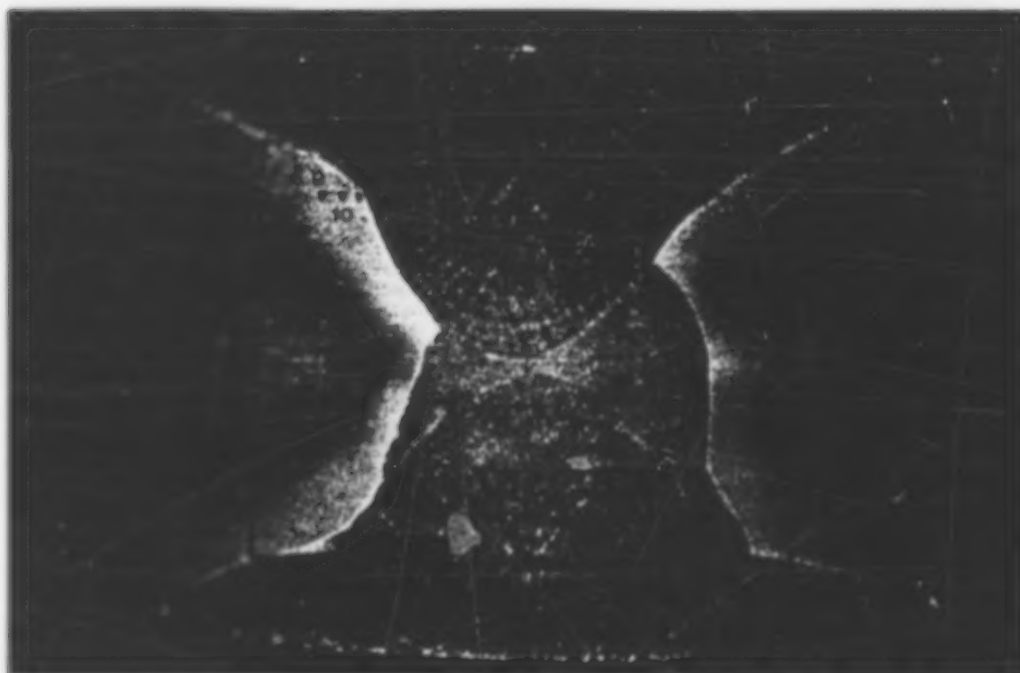


Figure B8. Weldment YHS-4.

Table B32. Microhardness Survey of Weldment YHS-4.

Location	HV ₁₀₀₀
1 - PM	212
2 - PM	201
3 - PM	202
4 - HAZ	200
5 - HAZ	224
6 - HAZ	237
7 - HAZ	241
8 - HAZ	248
9 - HAZ	248
10 - HAZ	263
11 - HAZ	287
12 - WM	248
13 - WM	244
14 - WM	250

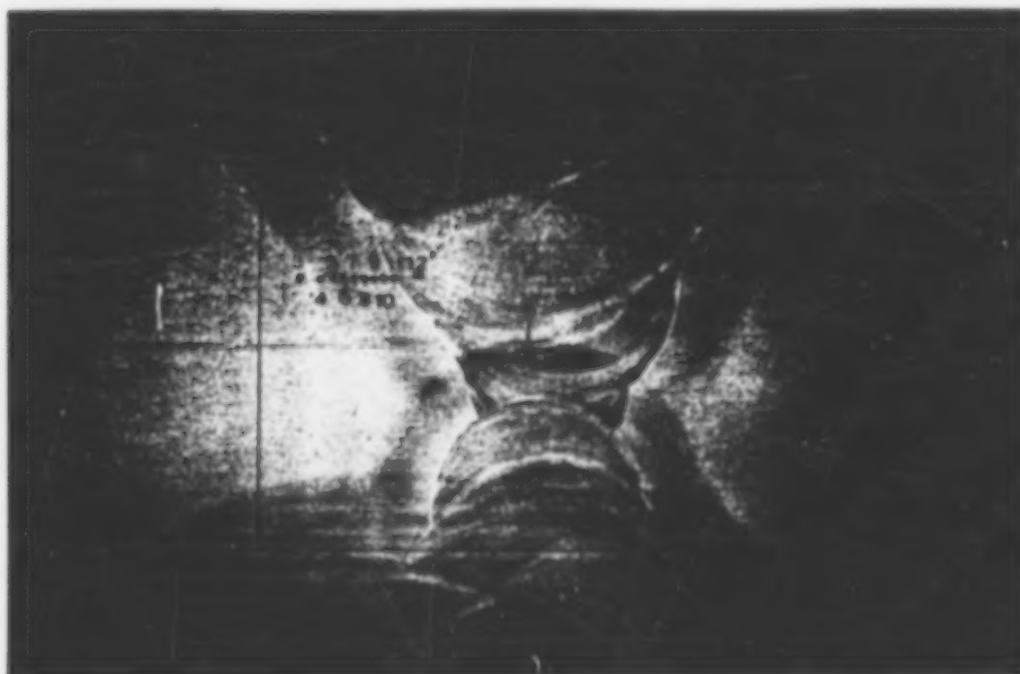


Figure B9. Weldment YLA-1.

Table B33. Microhardness Survey of Weldment YLA-1.

Location	HV ₁₀₀
1 - PM	199
2 - PM	213
3 - PM	217
4 - HAZ	218
5 - HAZ	226
6 - HAZ	241
7 - HAZ	250
8 - HAZ	241
9 - HAZ	240
10 - HAZ	241
11 - HAZ	249
12 - WM	237
13 - WM	248
14 - WM	239

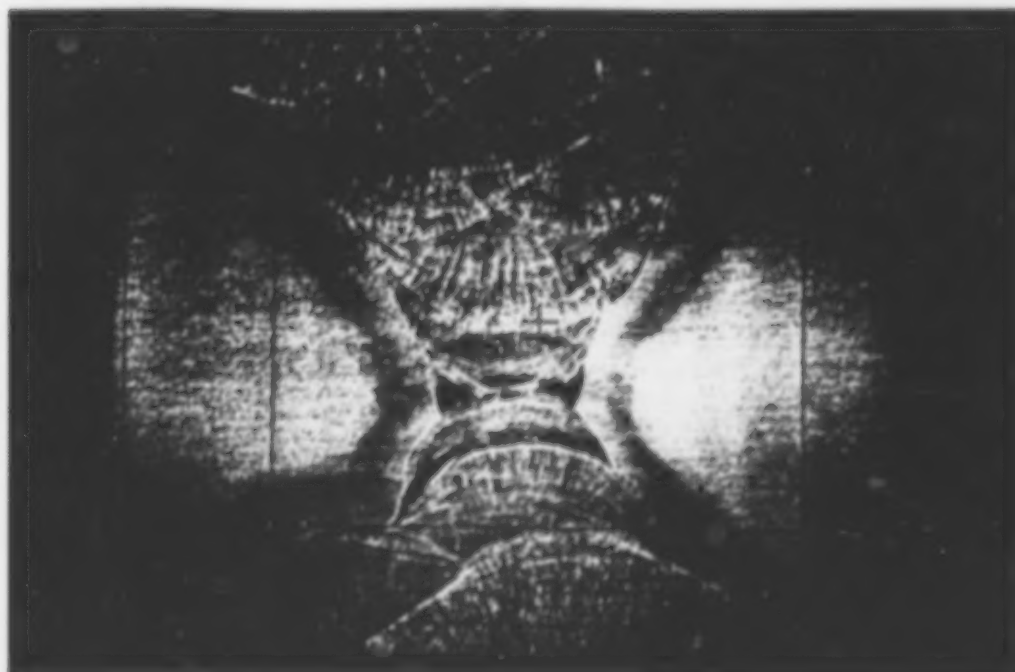


Figure B10. Weldment YLA-2.

Table B34. Microhardness Survey of Weldment YLA-2.

Location	HV _{0.05}
1 - PM	209
2 - PM	210
3 - HAZ	215
4 - HAZ	214
5 - HAZ	227
6 - HAZ	245
7 - HAZ	260
8 - HAZ	263
9 - WM	229
10 - WM	227
11 - WM	225

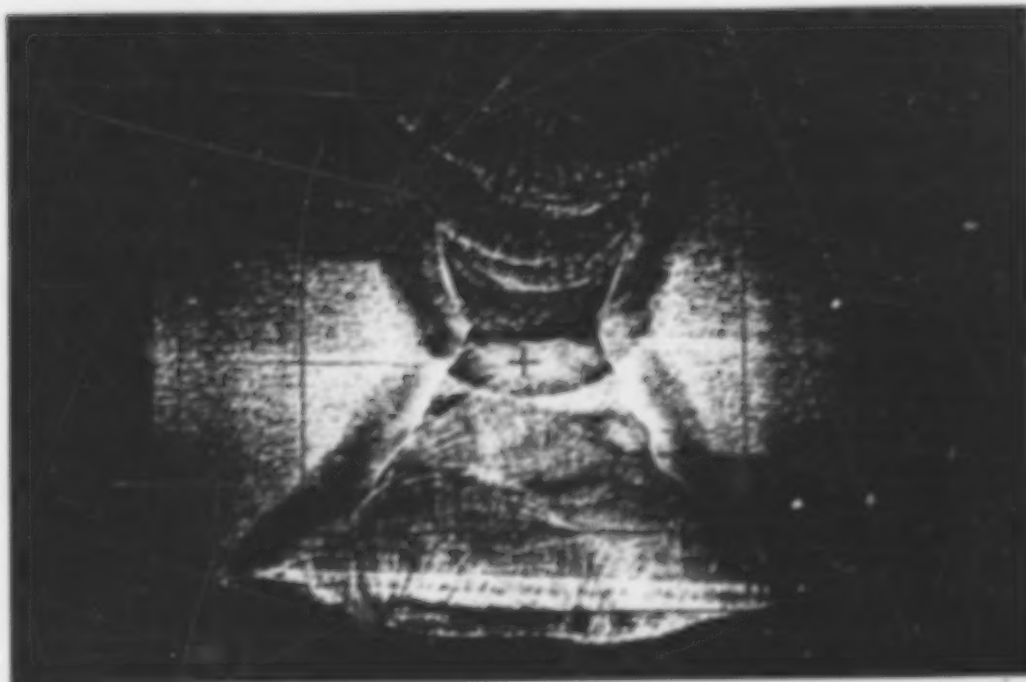


Figure B11. Weldment YLA-3.

Table B35. Microhardness Survey of Weldment YLA-3.

Location	HV _{0.05}
1 - PM	196
2 - PM	195
3 - PM	200
4 - PM	206
5 - PM	205
6 - PM	210
7 - HAZ	231
8 - HAZ	242
9 - HAZ	247
10 - HAZ	243
11 - WM	230
12 - WM	232
13 - WM	230

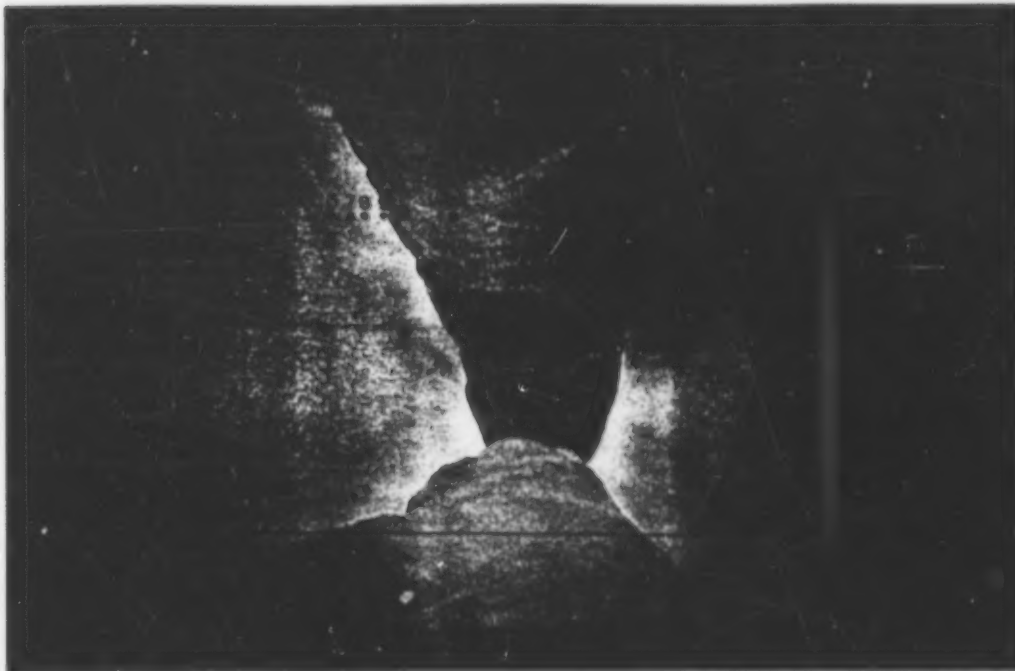


Figure B12. Weldment YLS-1.

Table B36. Microhardness Survey of Weldment YLS-1.

Location	HV ₁₀₀₀
1 - PM	194
2 - PM	192
3 - PM	198
4 - PM	196
5 - HAZ	198
6 - HAZ	208
7 - HAZ	231
8 - HAZ	244
9 - HAZ	256
10 - WM	216
11 - WM	229
12 - WM	221

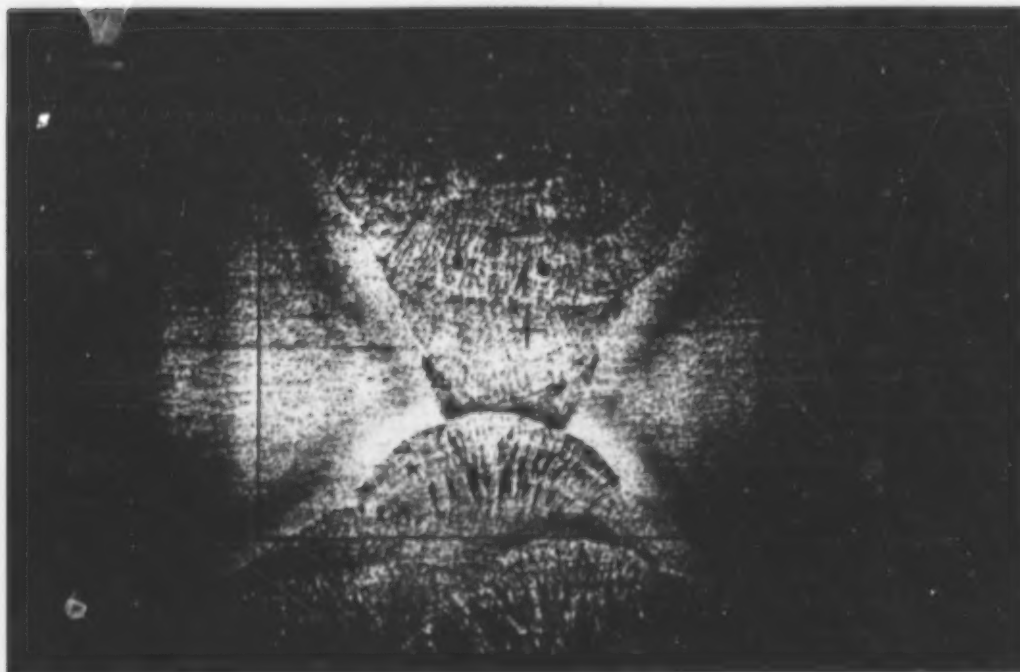


Figure B13. Weldment YLS-2.

Table B37. Microhardness Survey of Weldment YLS-2.

Location	HV ₁₀₀₀
1 - PM	198
2 - PM	200
3 - PM	198
4 - PM	207
5 - HAZ	203
6 - HAZ	205
7 - HAZ	214
8 - HAZ	238
9 - HAZ	256
10 - HAZ	266
11 - WM	218
12 - WM	233
13 - WM	223

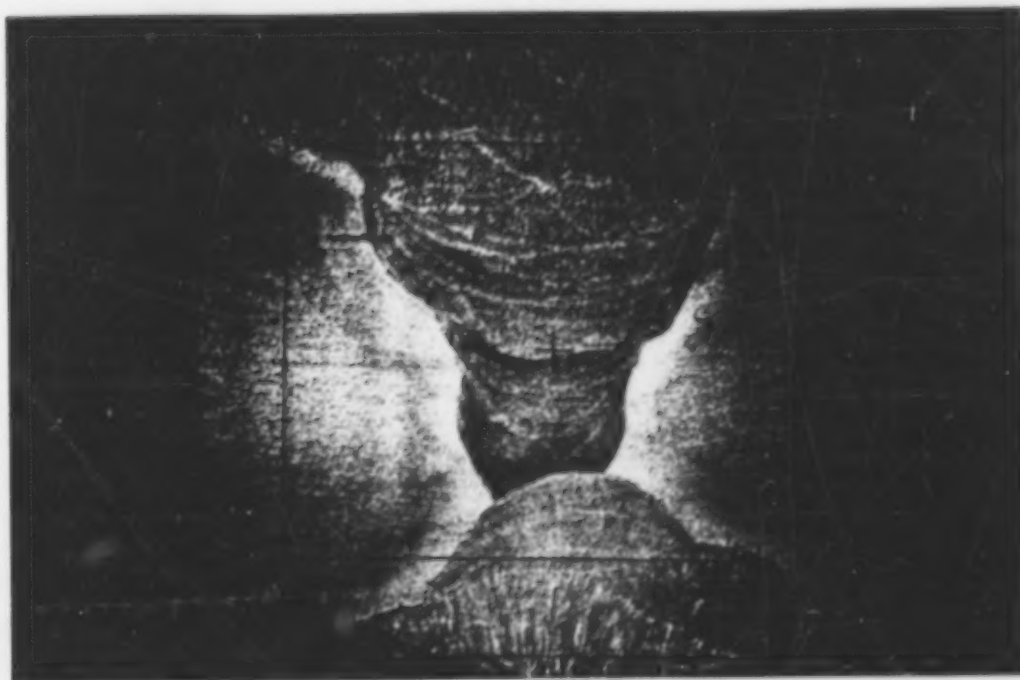


Figure B14. Weldment YLS-3.

Table B38. Microhardness Survey of Weldment of YLS-3.

Location	HV ₁₀₀₀
1 - PM	200
2 - PM	206
3 - PM	218
4 - HAZ	235
5 - HAZ	235
6 - HAZ	233
7 - HAZ	236
8 - HAZ	236
9 - HAZ	251
10 - HAZ	257
11 - HAZ	267
12 - HAZ	257
13 - WM	242
14 - WM	218
15 - WM	218

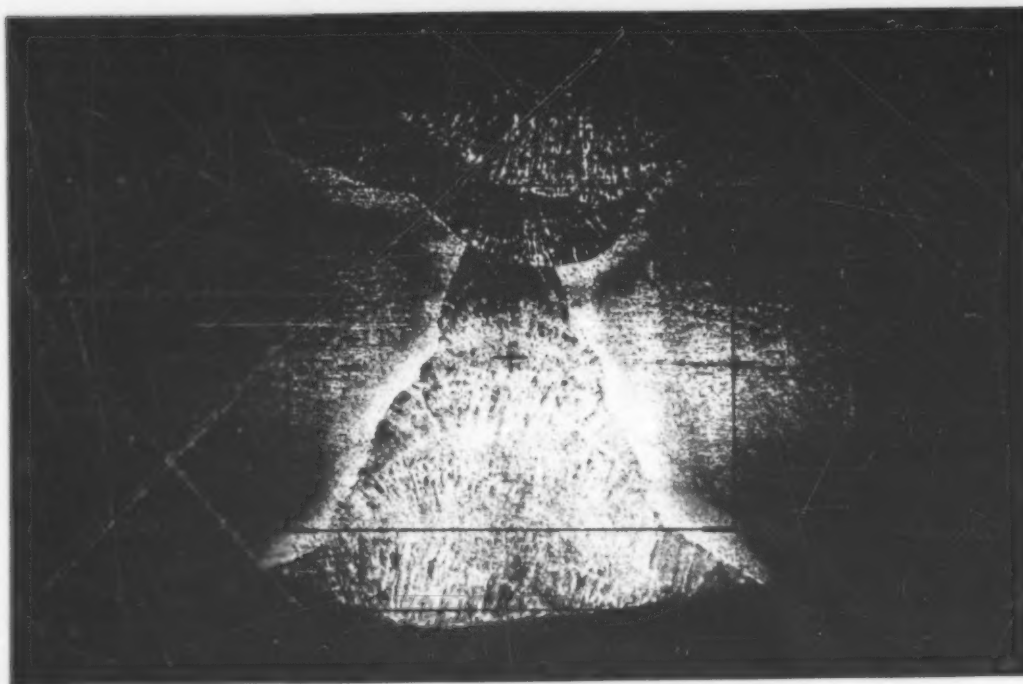


Figure B15. Weldment YLS-4.

Table B39. Microhardness Survey of Weldment YLS-4.

Location	HV ₁₀₀₀
1 - PM	207
2 - PM	211
3 - PM	211
4 - PM	215
5 - HAZ	208
6 - HAZ	228
7 - HAZ	250
8 - HAZ	270
9 - WM	264
10 - WM	263
11 - WM	251

TELEPHONE 519-621-8181
FAX 519-621-7700

The Galt Testing Laboratories Limited

ESTABLISHED 1929

Chemical Analysis of
Malleable, Meehanite, Ductile
and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slags, Etc.

CHEMISTS and METALLURGISTS

15 HIGHRIDGE COURT (AT PINEBUSH ROAD)
P.O. BOX 363
CAMBRIDGE (GALT), ONTARIO
N1R 7L3

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact.
Metallography:
Sand Testing:
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE B40
Customer P.O.: RD5733

Laboratory Sample I.D. #: A1202

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 3/4" Thick

YHA-1

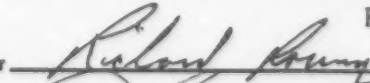
Specimen Dimensions	1.500 X 0.763	in.
Area of Cross Section	1.14	sq. in.
Maximum Load	105,200	lbf
Tensile Strength	92,500	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.
The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

This report relates only to the specimen or specimens tested and does not guarantee
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or testing or any failure or omission in regard thereto.

The Galt Testing Laboratories

Per  Richard Rounge
Technician
 Bill Bartlett
Senior Technician

TELEPHONE 519-621-8191
FAX 519-621-7700

The Galt Testing Laboratories Limited

ESTABLISHED 1929

Chemical Analysis of
Malleable, Meehanite, Ductile
and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slags, Etc.

CHEMISTS and METALLURGISTS

15 HIGHRIIDGE COURT (AT PINEBUSH ROAD)
P.O. BOX 363
CAMBRIDGE (GALT), ONTARIO
N1R 7L3

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography:
Sand Testing:
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE B41

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1203

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 3/4" Thick

YHA-5

Specimen Dimensions	1.498 X 0.764	in.
Area of Cross Section	1.14	sq. in.
Maximum Load	105,400	lbf
Tensile Strength	92,500	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
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damage arising directly or indirectly out of, or in connection with any such inspection
or testing or any failure or omission in regard thereto.

The Galt Testing Laboratories

Per Richard Rount Richard Rount
Technician
Per Bill Bartlett Bill Bartlett
Senior Technician

TELEPHONE 519-621-5191
FAX 519-621-7700

The Galt Testing Laboratories Limited

ESTABLISHED 1929

Chemical Analysis of
Malleable, Meehanite, Ductile
and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slags, Etc.

CHEMISTS and METALLURGISTS

15 HIGHRIDGE COURT (AT PINEBUSH ROAD)
P.O. BOX 363
CAMBRIDGE (GALT), ONTARIO
N1R 7L3

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography:
Sand Testing:
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE B42

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1204

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 3/4" Thick

YHS-1

Specimen Dimensions	1.501 X 0.765	in.
Area of Cross Section	1.15	sq. in.
Maximum Load	106,600	lbf
Tensile Strength	92,500	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

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damage arising directly or indirectly out of, or in connection with any such inspection
or testing or any failure or omission in regard thereto.

The Galt Testing Laboratories

Per Richard Rount Richard Rount
Technician
Per Bill Bartlett Bill Bartlett
Senior Technician

TELEPHONE 519-621-9191
FAX 519-621-7700

Chemical Analysis of
Manganese, Molybdenum, Nickel
and Cast Irons; Phosphorus
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Cast, Cast, Limestone,
Slags, Etc.

The Galt Testing Laboratories Limited

CHEMISTS and METALLURGISTS

15 HIGHRIDGE COURT (AT PINEBUSH ROAD)
P.O. BOX 363
CAMBRIDGE (GALT), ONTARIO
N1R 7L3

ESTABLISHED 1980

Metals and Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography,
Sand Testing,
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE B43

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1205

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 3/4" Thick

YHS-5

Specimen Dimensions	1.501 X 0.767	in.
Area of Cross Section	1.15	sq. in.
Maximum Load	107,000	lbf
Tensile Strength	93,000	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

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or testing or any failure or omission, in regard thereto.

The Galt Testing Laboratories

Per Richard Rount Richard Rount
Technician
Per Bill Bartlett Bill Bartlett
Senior Technician

TELEPHONE 519-821-6191
FAX 519-821-7700

The Galt Testing Laboratories Limited

ESTABLISHED 1958

Chemical Analysis of
Metals, Mechanical, Ductile
Cast Irons, Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Cast, Cast, Limestone,
Slag, Etc.

CHEMISTS and METALLURGISTS

15 HIGHRIDGE COURT (AT PINEBUSH ROAD)
P.O. BOX 363
CAMBRIDGE (GALT), ONTARIO
N1R 7L3

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography,
Sand Testing,
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE B44

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1200

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 3/4" Thick

YLA-1

Specimen Dimensions	1.498 X 0.762	in.
Area of Cross Section	1.14	sq. in.
Maximum Load	103,700	lbf
Tensile Strength	91,000	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

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The Galt Testing Laboratories

Per Richard Rount Richard Rount
Technician
Per Bill Bartlett Bill Bartlett
Senior Technician

TELEPHONE 519-821-6181
FAX 519-821-7780

Chemical Analysis of
Metals, Steels, Castings, Ductile
and Cast Irons, Plastics,
Alloys and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronze;
Coal, Coke, Limestone,
Slags, Etc.

The Galt Testing Laboratories Limited

CHEMISTS and METALLURGISTS

15 HIGHRIDGE COURT (AT PINEBUSH ROAD)
P.O. BOX 383
CAMBRIDGE (GALT), ONTARIO
N1R 7L3

ESTABLISHED 1939

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography,
Grain Training,
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE B45

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1200

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 3/4" Thick

YLA-1

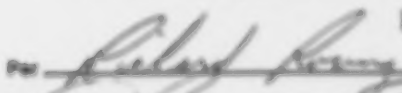
Specimen Dimensions	1.498 X 0.762	in.
Area of Cross Section	1.14	sq. in.
Maximum Load	103,700	lbf
Tensile Strength	91,000	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.
The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

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or testing or any failure or omission in regard thereto.

The Galt Testing Laboratories

Per  Richard Rount
Technician
Per  Bill Bartlett
Senior Technician

TELEPHONE 519-821-6101
FAX 519-821-7708

Chemical Analysis of
Metals, Alloys, Castings,
and Coal Irons, Phos-
phorus and Sulfur Content,
Zinc and Manganese Levels,
Brass and Bronze,
Cast, Cast, Limestone,
Slag, Etc.

The Galt Testing Laboratories Limited

CHEMISTS and METALLURGISTS

15 HIGHRIDGE COURT (AT PINEBUSH ROAD)

P.O. BOX 363

CAMBRIDGE (GALT), ONTARIO

N1R 7L3

ESTABLISHED 1989

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography,
Sand Testing:
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE B46

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1206

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 3/4" Thick

YLS-1

Specimen Dimensions	1.500 X 0.757	in.
Area of Cross Section	1.14	sq. in.
Maximum Load	105,200	lbf
Tensile Strength	92,500	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

Samples returned at customer's request and expense; otherwise
samples retained one year from date of test.

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or testing or any failure or omission in regard thereto.

The Galt Testing Laboratories

Per Richard Rount Richard Rount
Technician
Per Bill Bartlett Bill Bartlett
Senior Technician

TELEPHONE 519-821-8191
FAX 519-821-7700

The Galt Testing Laboratories Limited

ESTABLISHED 1888

Chemical Analysis of
Metals, Mechanisms, Ductile
and Cast Irons; Plain,
Alloyed and Stainless Steels;
Zinc and Aluminum Alloys;
Brass and Bronzes;
Coal, Coke, Limestone,
Gases, Etc.

CHEMISTS and METALLURGISTS

15 HIGHRIDGE COURT (AT PINEBUSH ROAD)

P.O. BOX 363

CAMBRIDGE (GALT), ONTARIO

N1R 7L3

Mechanical Testing:
Tension, Hardness, Bend,
Notched Bar Impact,
Metallography,
Sand Testing,
Reports

Welding Institute of Canada
391 Burnhamthorpe Road East
Oakville, Ontario
L6J 6C9

TABLE B47

Customer P.O.: RD5733

Laboratory Sample I.D. #: A1207

Report Date: October 24, 1989

Weld Specimen, Marked: RC343
12" Long x 2" Wide x 3/4" Thick

YLS-5

Specimen Dimensions	1.499 X 0.748	in.
Area of Cross Section	1.12	sq. in.
Maximum Load	104,500	lbf
Tensile Strength	93,500	psi

The test was conducted in accordance with ASME BOILER AND
PRESSURE VESSEL CODE, SECTION IX, 1989.

The specimen was tested as received and fractured outside
the weld.

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The Galt Testing Laboratories

Per Richard Rount Richard Rount
Technician
Per Bill Bartlett Bill Bartlett
Senior Technician

Table B48

Bend Test Report

Client: Trans Canada

Client P.O. Number:

WIC Contract Number: RC343

Test Standard:

Specimen Standard: ANST/AWS D1.1-88*

Specimen Material: Steel Y, Weldment

Specimens Machined by:

9.5 x 14.3 mm specimen

Specimen Number	Specimen Type	Defects	Result
YLA-1	side bend	NONE	pass
-2	side bend	NONE	pass
-3	side bend	NONE	pass
YLS-1	side bend	NONE	pass
-2	side bend	0.5mm long separation at the fusion boundary	pass
-3	side bend	NONE	pass
YHA-1	side bend	NONE	pass
-2	side bend	NONE	pass
-3	side bend	NONE	pass
YHS-1	side bend	NONE	pass
-2	side bend	NONE	pass
-3	side bend	NONE	pass
YLA-4	side bend	NONE	pass
YLS-4	side bend	NONE	pass
YHA-4	side bend	NONE	pass
YHS-4	side bend	NONE	pass

Comments: 180 deg. bend around 25.4 mm radius

Date: Nov./89

Tested by: JMI

Witnessed by:

Project Engineer: S.R.B.

Table B49

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: HAZ

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
YHA-1	-46		325		100	2.26
-2	-46		273		100	2.41
-3	-46		67		20	0.99
-4	-46		119		35	1.60
-5	-46		250		85	2.29
-6	-46		292		80	2.08
-7	-46		302		100	2.39
-8	-46		240		65	2.52
-9	-46		215		40	2.41
-10	-46		34		8	0.51
-11	-46		202		40	2.46
-12	-46		210		50	2.52
-13	-46		15		5	0.20
-14	-46		283		90	2.26
-15	-46		77		15	0.97
-16	-46		325		100	NB

Comments: Steel Y

Date: Oct./89

As-welded HAZ in sub-arc weldment

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B50

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: HAZ

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
YHS-1	-46		207		100	2.24
-2	-46		270		100	2.44
-3	-46		202		100	2.24
-4	-46		270		100	2.31
-5	-46		177		85	1.83
-6	-46		279		100	2.26
-7	-46		234		100	1.83
-8	-46		325+		100	2.08
-9	-46		325+		100	NB
-10	-46		240		95	NB
-11	-46		325+		100	NB
-12	-46		310		75	2.34
-13	-46		325+		100	NB
-14	-46		259		60	2.46
-15	-46		304		90	1.73
-16	-46		67		10	0.81

Comments: Steel Y

Date: Oct./89

Stress-relieved HAZ of sub-arc
weldment

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B51

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: HAZ

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
YLA-1	-46		250		85	2.44
-2	-46		168		85	2.01
-3	-46		272		85	2.41
-4	-46		174		90	2.13
-5	-46		197		60	2.13
-6	-46		315		100	2.44
-7	-46		305		90	2.51
-8	-46		267		100	2.26
-9	-46		23		80	0.43
-10	-46		298		100	2.44
-11	-46		325+		100	NB
-12	-46		325+		100	NB
-13	-46		325+		100	NB
-14	-46		260		85	2.52
-15	-46		267		70	2.49
-16	-46		186		100	2.21

Comments: Steel Y

Date: Oct./89

As-welded HAZ in shielded metal arc weldment.

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B52

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: HAZ

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
YLS-1	-46		233		80	2.49
-2	-46		239		100	2.39
-3	-46		220		100	2.18
-4	-46		194		100	2.26
-5	-46		225		85	2.31
-6	-46		175		100	2.11
-7	-46		212		100	2.21
-8	-46		191		100	2.13
-9	-46		170		90	2.16
-10	-46		195		95	2.24
-11	-46		148		70	1.83
-12	-46		215		70	2.34
-13	-46		325+		100	NB
-14	-46		21		20	0.43
-15	-46		247		95	2.39
-16	-46		182		80	2.24

Comments: Steel Y

Date: Oct./89

Stress-relieved HAZ of
shielded metal arc weldment.

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B53

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: WM

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
YHA-1 -2	-46 -46	WM WM	50 54		20 15	0.66 0.74
-3 -4	-46 -46	WM WM	46 28		20 20	0.58 0.43
-5	-46	WM	48		20	0.029

Comments: Steel Y

Date: Oct./89

As-welded weld metal of
sub arc weldment

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B54

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: WM

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
YHS-1	-46	WM	24		10	0.20
-2	-46	WM	12		10	0.076
-3	-46	WM	22		10	0.20
-4	-46	WM	13		8	0.10
-5	-46	WM	14		10	0.10

Comments: Steel Y

Date: Oct./89

Stress-relieved weld metal of
sub arc weld.

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B55

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: WM

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
YLA-1 -2	-46 -46	WM WM	48 47		25 25	0.66 0.58
-3 -4	-46 -46	WM WM	78 49		45 25	0.94 0.53
-5	-46	WM	59		35	0.71

Comments: Steel Y

Date: Oct./89

As-welded weld metal of shielded metal arc weld.

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.

Table B56

Charpy Impact Test Report

Client: Transport Canada

Specimen Standard: ASTM E23

Client P.O. Number:

Specimen Type: WM

WIC Contract Number: RC343

Specimen Material: Steel Y

Test Standard: ASTM E23

Specimen Number	Test Temperature (°C)	Notch Location	Absorbed Energy (J)	Average Energy (J)	Shear (%)	Lateral Expansion (mm)
YLS-1 -2	-46 -46	WM WM	35 22		10 25	0.41 0.25
-3 -4	-46 -46	WM WM	36 40		20 25	0.41 0.50
-5	-46	WM	32		25	0.33

Comments: Steel Y, hot formed

Date: Oct./89

Stress-relieved weld metal of
shielded metal arc weld

Tested by: J.M.I.

Witnessed by:

Project Engineer: S.R.B.



APPENDIX - C

STEEL SPECIFICATIONS

Mill Reports for Steels X & Y

Steel Specification for TC-135

Steel Specification for TC-128

ASTM Designation A808/A808M-88

TC-135 Steel Supplementary Requirements

ASTM Designation A20/A20M

MILL REPORT FOR STEEL X FROM SOURCE A

Plate for the AAR Tank Car steel Evaluation:

Plate Number: 322225

Heat Number: 9236M

Size: 0.5625 x 96 x 150 in.

The chemical analysis was as follows:

0.12 C, 1.24 Mn, 0.007 S, 0.015 P, 0.28 Si, 0.04 Cr, 0.09 Ni, 0.02 Cu, 0.01 Mo,
0.053 Al, 0.036 Cb, 0.052 V.

The mechanical properties were as follows:

Yield strength: 61.7 ksi (drop of beam), tensile strength: 84.4 ksi and elongation on
2" gauge length: 38 %.

CVNL at -50° F: 34, 43 and 53 ft.lbs.

The toughness values are from the back of the plate. The toughness values from the front end of the plate are higher due to the colder finishing temperatures on the end of the plate. The design practice was to meet the minimums of the specification in the middle of the plate which usually exhibits the lowest toughness values.

MILL REPORT FOR STEEL Y FROM SOURCE B

As outlined in our conversations, Source B had agreed to supply our best candidate steel for controlled rolled Grade B and you now have the 0.75 x 130 x 120 in. plate.

This material meets the draft specification ASTM A8XX dated January 1988 with the exception of the molybdenum content. We plan to propose that, since the draft specification includes a maximum carbon equivalent of 0.47 max (IIW formula), that Note 3 under the chemistry table (Table I) be eliminated.

Chemistry and test results for this plate are as follows:

Heat 823148 Charge 702 Rolled 89.02.13

0.06 C, 1.53 Mn, 0.009 P, 0.003 S, 0.35 Si, 0.15 Cr, 0.37 Mo, 0.058 V, 0.052 Nb,
0.048 Acid sol. Al, and 0.010 N.

Carbon equivalent - 0.432

Yield strength - 66.5 ksi

Ultimate tensile strength - 89.1 ksi

Charpy transverse - CV-T 127 ft.lbs. at -50° .

RAILROAD TANK CAR SAFETY RESEARCH AND TEST PROJECT

AN RPI-AAR COOPERATIVE PROGRAM

ENGINEERING JAN 28 1988

PROJECT REVIEW COMMITTEE

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J.F. McCarthy, Sr. Vice President
ACF Industries, Inc.

W.R. Wallace, President
and Chief Executive Officer
Trinity Industries, Inc.

January 18, 1988

C.C. Comiskey
Sinclair
in f.

PROJECT DIRECTOR
Earl Phillips

DEPUTY PROJECT DIRECTOR
Lee Olson

Mr. P. G. Kinnecom
Mechanical Division
Association of American Railroads
50 "F" Street, N.W.
Washington, D. C. 20001

SUBJECT: AAR TCC Docket T95.7-81, Use of Steels
in Tank Cars

Dear Paul:

At the January 11, 1988 Tank Car Steel T/F meeting I agreed to send you the following documents for distribution to the Tank Car Committee:

- (1) Latest draft of the proposed specification for the new steels. This is labelled "Draft - January 18, 1988" and contains only two small changes (underlined) over the previous October 21, 1987 draft to which sample plates have been ordered for the forthcoming test program.
- (2) Exhibits 6A, 7A, 8A covering CVN and DT test results for specimens oriented transverse to the direction of rolling. These were not included in report RA-03-7-53, but are derived from the detailed test results contained in Appendix A to that report.

Reply to: Project Director - Tank Car Research
Association of American Railroads, Technical Center
3140 South Federal Street, Chicago, Illinois 60616
312-567-3607

Mr. P. G. Kinnecom
page 2
January 18, 1988

- (3) Exhibits 6, 7, 8 covering CVN and DT test results for longitudinal specimens. These were presented in RA-03-7-53, and are included again here for convenience of comparison.

Sincerely,



E. A. Phillips
Project Director

EAP/smj

Enclosure

cc: S. A. Coughlin (ACF)
T. H. Dalrymple (UTC)
B. J. Damiani (UTC)
W. L. Finn (ACF)
P. B. Heideman (UTC)
E. Mowatt-Larssen (GAT)
L. L. Olson (AAR)
S. W. Smith (Trinity)

PRESSURE VESSEL PLATES, HIGH STRENGTH LOW ALLOY
(Draft - January 18, 1988)

(Note: Changes over previous draft of October 21, 1987 are underlined)

1. SCOPE

- 1.1 This specification covers steel plates intended primarily for use in welded pressure vessels and tank car tanks where improved weldability and low temperature notch toughness are desired.
- 1.2 Three grades are included. Grades A and B have 70 ksi and 80 ksi tensile strengths, respectively, and are produced by the control rolled process (CR) or the thermo-mechanical control process (TMCP). Grade C has 80 ksi tensile strength and is for use in the normalized condition.
- 1.3 The TMCP method consists of rolling-reduction and cooling rate controls which result in mechanical properties in the finished plate that are equivalent to those attained using conventional rolling and heat treating processes which entail reheating after rolling to achieve desired properties (i.e., normalizing or quenching and tempering).
- 1.4 Due to the inherent characteristics of the TMCP method, the plates of Grades A and B formed at elevated temperatures may sustain substantial losses in strength and toughness. Grades C plates may be affected by elevated temperatures but are generally less vulnerable to damage. The plates of Grades A, B and C may be formed and post-weld heat-treated at elevated temperatures, providing requirements of 7.1 are met.
- 1.5 The maximum nominal thickness of plates furnished under this specification may not exceed 1 in. (25 mm).
- 1.6 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore each system must be used independently of the other. Combining values from the two systems may result in non-conformance with the specification.

2. APPLICABLE DOCUMENTS

2.1 ASTM Standards:

A20/A20M Specification for General Requirements for Steel Plates for Pressure Vessels

A435/A435M Specification for Straight-Beam Ultrasonic Examination of Steel Plates

A577/A577M Specification for Ultrasonic Angle-Beam
Examination of Steel Plates

A578/A578M Specification for Straight-Beam Ultrasonic
Examination of Plain and Clad Steel Plates for Special
Applications

3. GENERAL REQUIREMENTS AND ORDERING INFORMATION

- 3.1 Material supplied to this material specification shall conform to Specification A20/A20M. These requirements outline the testing and retesting methods and procedures, permissible variations in dimensions, quality and repair of defects, marking, loading, etc.
- 3.2 Specification A20/A20M also establishes the rules for ordering information which should be complied with when purchasing material to this specification.
 - 3.2.1 When the material is to be subjected to elevated temperature forming or post-weld heat treatment, the order must indicate the temperatures and times-at-temperature that will be utilized in such operations. (See 7.1 and Specification A20/A20M, Supplementary Requirement S3.)
- 3.3 In addition to the basic requirements of this specification, certain supplementary requirements are available when additional control, testing, or examination is required to meet end use requirements.
- 3.4 The purchaser is referred to the listed supplementary requirements in this specification and to the detailed requirements in Specification A20/A20M.
- 3.5 If the requirements of this specification are in conflict with the requirements of Specification A-20/A20M, the requirements of this specification shall prevail.

4. MANUFACTURE

- 4.1 Steelmaking Practice--The steel shall be killed and shall be made to a fine austenitic grain size practice.
- 4.2 The plates for Grade A and B shall be produced by the control rolled or thermo-mechanical control process.

5. HEAT TREATMENT

- 5.1 Grades A and B plates shall be supplied in the as-rolled condition.
- 5.2 Grade C plates shall be in the normalized condition after final fabrication.

6. CHEMICAL COMPOSITION

- 6.1 The chemical composition on heat analysis shall conform to the requirements listed in Table 1, except as otherwise provided in Supplementary Requirement S17 of Specification A20/A20M when that requirement is involved.

7. MECHANICAL REQUIREMENTS

- 7.1 When the material is to be subjected to elevated temperature forming or post-weld heat treatment, the test coupons shall be subjected to heat treatment to simulate such fabrication operations. The maximum stress relief temperature for Grades A and B shall be 1200°F. (See 3.2.1 and Specification A20/A20M, Supplementary Requirement S3.)
- 7.2 Tension Test Requirements
 - 7.2.1 For Grades A and B, two tensile tests shall be made from each plate as-rolled. One test coupon shall be taken from a corner of the plate on each end.
 - 7.2.2 For Grade C, one tensile test shall be made from each plate. Test coupons shall be normalized.
 - 7.2.3 The plates as represented by the tension-test specimens shall conform to the requirements shown in Table 2.
- 7.3 Notch Toughness Test Requirements
 - 7.3.1 For Grades A and B, two longitudinal Charpy V-notch tests shall be made in accordance with Specification A20/A20M. One test coupon shall be taken from a corner of the plate on each end.
 - 7.3.2 For Grade C, one longitudinal Charpy V-notch test shall be made in accordance with Specification A20/A20M.
 - 7.3.3 The test results of shall meet an average value (3 specimens) of 25 ft. lbs. at -50°F (34J at -46°C). The minimum for one value is 20 ft. lbs. (27J).

Charpy

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall not apply unless specified in the order.

A list of standardized supplementary requirements for use at the option of the purchaser are included in Specification A20/A20M. Several of those that are considered for use with this specification are listed below by title. Other tests may be performed by agreement between the supplier and the purchaser.

- S1. Vacuum Treatment,
- S2. Product Analysis,
- S3. Simulated Post-Weld Heat Treatment of Mechanical Test Coupons,
- S5. Charpy V-Notch Impact Test,
- S6. Drop Weight Test,
- S8. Ultrasonic Examination in accordance with Specification A435/A435M,
- S9. Magnetic Particle Examination,
- S10. Charpy V-Notch Test Curve,
- S11. Ultrasonic Examination in accordance with Specification A577/A577M,
- S12. Ultrasonic Examination in accordance with Specification A578/A578M,
- S13. NDT Temperature Determination,
- S14. Bend Test (pin diameter subject to agreement),
- S17. Vacuum Carbon-Deoxidized Steel,
- S18. Unspecified Elements, and
- S19. Restricted Chemical Requirements.

TABLE 1

CHEMICAL COMPOSITION

<u>ELEMENT</u>	<u>Grade A</u>	<u>Grade B</u>	<u>Grade C</u>
	HEAT AND PRODUCT ANALYSIS(3)	HEAT AND PRODUCT ANALYSIS(3)	HEAT AND PRODUCT ANALYSIS(3)
Carbon	0.12 Max.	0.16 Max.	0.22 Max.
Manganese	1.00-1.75	1.00-1.75	1.00-1.60
Phosphorous	0.035 Max.	0.035 Max.	0.035 Max.
Sulphur	0.010 Max.	0.010 Max.	0.010 Max.
Silicon (1)	0.10-0.55	0.10-0.55	0.10-0.55
Columbium	0.06 Max.	0.06 Max.	0.05 Max.
Vanadium	0.11 Max.	0.11 Max.	0.12 Max.
Columbium plus Vanadium	0.16 Max.	0.16 Max.	0.16 Max.
Nitrogen	--	--	0.03 Max.
Carbon Equivalent (2)	0.42 Max.	0.47 Max.	0.52 Max.

(1) If total aluminum content is 0.02% or greater, the requirement for a minimum silicon content may be deleted at the option of the producer.

(2) As calculated using carbon equivalent formula:

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15$$

(3) The limits on unspecified elements per ASTM A20 paragraph 7.1.1 apply

TABLE 2

TENSILE REQUIREMENTS

	<u>Grade A</u>	<u>Grade B</u>	<u>Grade C</u>
	ksi (MPa)	ksi (MPa)	ksi (MPa)
Tensile Strength	70-90 (485-620)	80-100 (550-690)	80-100 (550-690)
Yield Strength	50 (345)	60 (415)	60 (415)
Elongation in 8 In. Minimum Percent (1)	18 (200 mm)	15	18
Elongation in 2 In. Minimum Percent (1)	22 (50 mm)	20	23

(1) - See Specification A20/A20M

EXHIBIT 6A

CHARPY V-NOTCH IMPACT TEST RESULTS, TRANSVERSE SPECIMENS, BASE METAL

(Battelle, Appendix A)

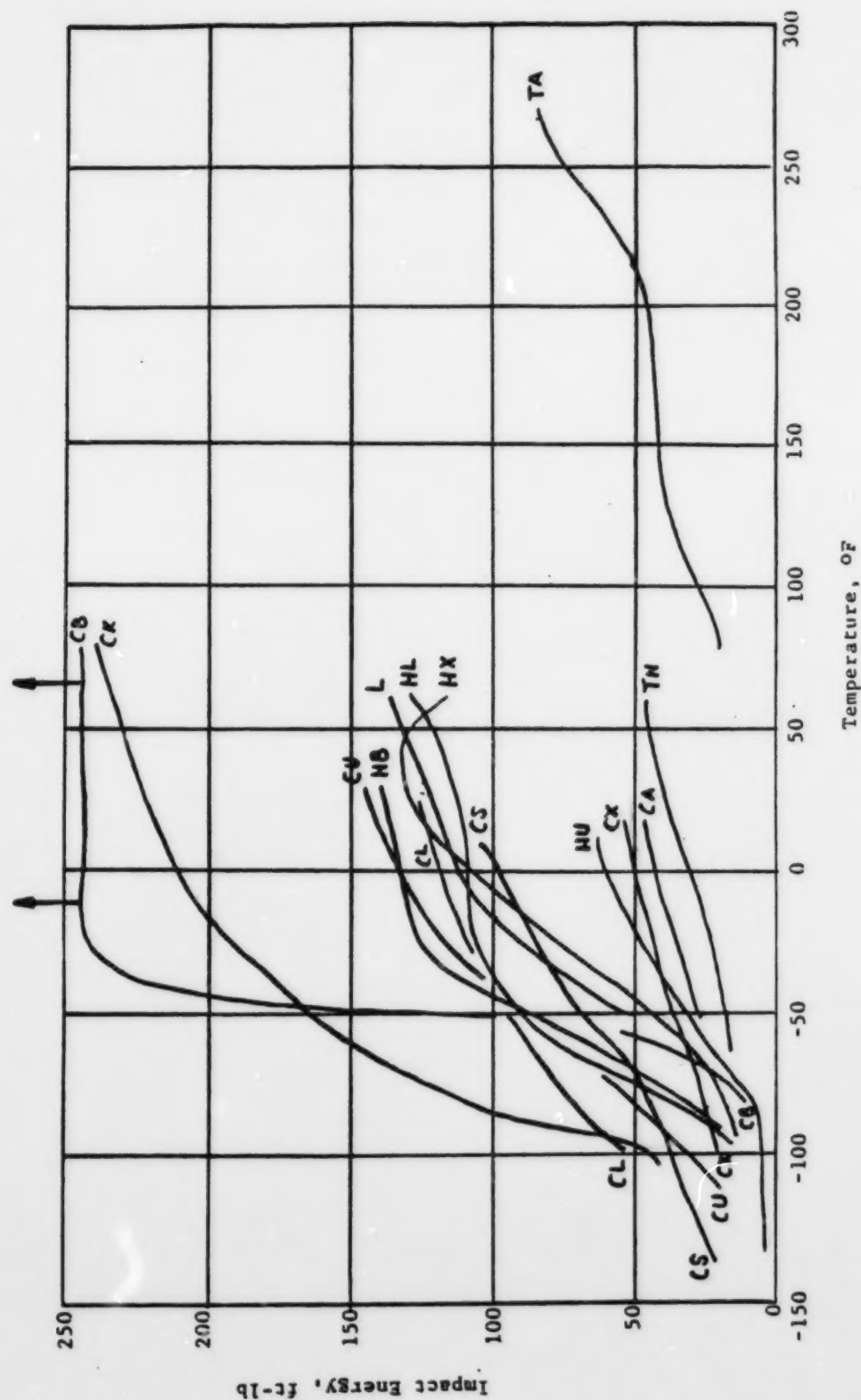


EXHIBIT 7A

DYNAMIC TEAR TEST RESULTS, FULL THICKNESS (3/4") TRANSVERSE SPECIMENS, BASE METAL.

(Battelle, Appendix A)

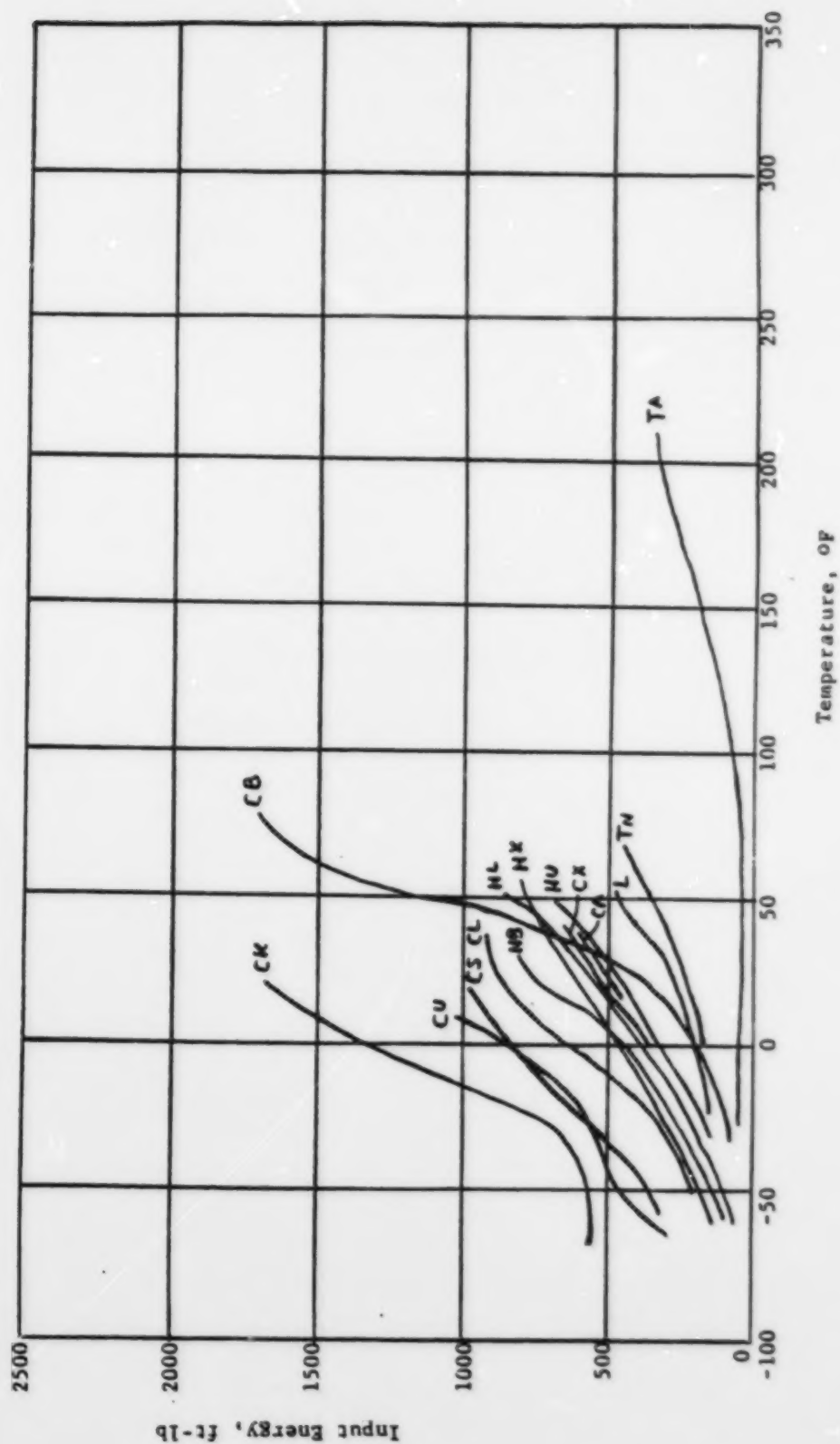


EXHIBIT 8 A

IMPACT PROPERTIES AND GRAIN SIZE OF BASE METAL

(Battelle, Appendix A)

Steel	NDT °F	CVN @ -50°F ft-lb ^{1/2}	Grain Size ^{4/}	
			Max.	Min.
TA	+30	(27) 32 (0 (+80°F)	9	8
TN	-40	40 (17)	10.5	9.5
L	-20	40 (50)	10	8.5
CA	-70	95 (27)	10.5	10
CX ^{2/}	-70	106 (36)	11	10
CB	-40	150 (130)	10.5	9.5
CK	-70	210 (155)	9.5	9.5
CL	-70	132 (93)	11	10
CS	-100	165 (67)	10	10
CU	-80	182 (99)	11	10
HB	-40	130 (85)	11	10.5
HL	-50	100 (85)	11	10
HX ^{2/}	-50	55 (43)	11	10
HS	Note 3	Note 3	10.5	9.5
HU	-50	77 (32)	9.5	9.5

Note: Circled values are taken from curves in Exhibit 6A for transverse specimens.

1/ Values taken from curves for longitudinal specimen tests, Exhibit 6.

2/ CX and HX non-stress relieved. All others stress relieved at 1100°F for one hour.

3/ Data questionable. Will be retested.

4/ Per ASTM Spec. E112 utilizing the intercept procedure.

EXHIBIT 6

CHARPY V-NOTCH IMPACT TEST RESULTS, LONGITUDINAL SPECIMENS, BASE METAL
(Battelle, Appendix A)

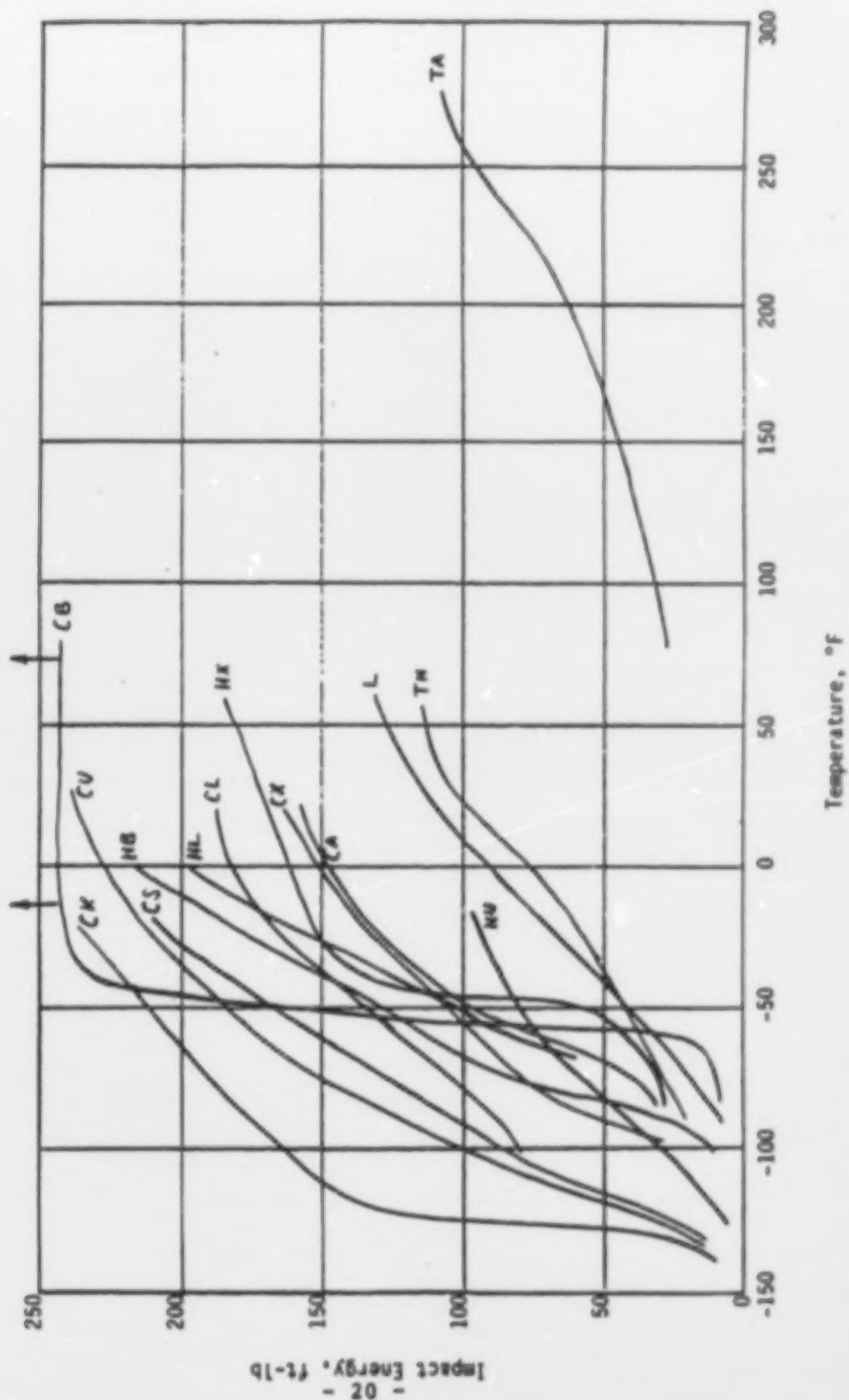


EXHIBIT 7

DYNAMIC TEAR TEST RESULTS, FULL THICKNESS (3/4") LONGITUDINAL SPECIMENS, BASE METAL
(Battelle, Appendix A)

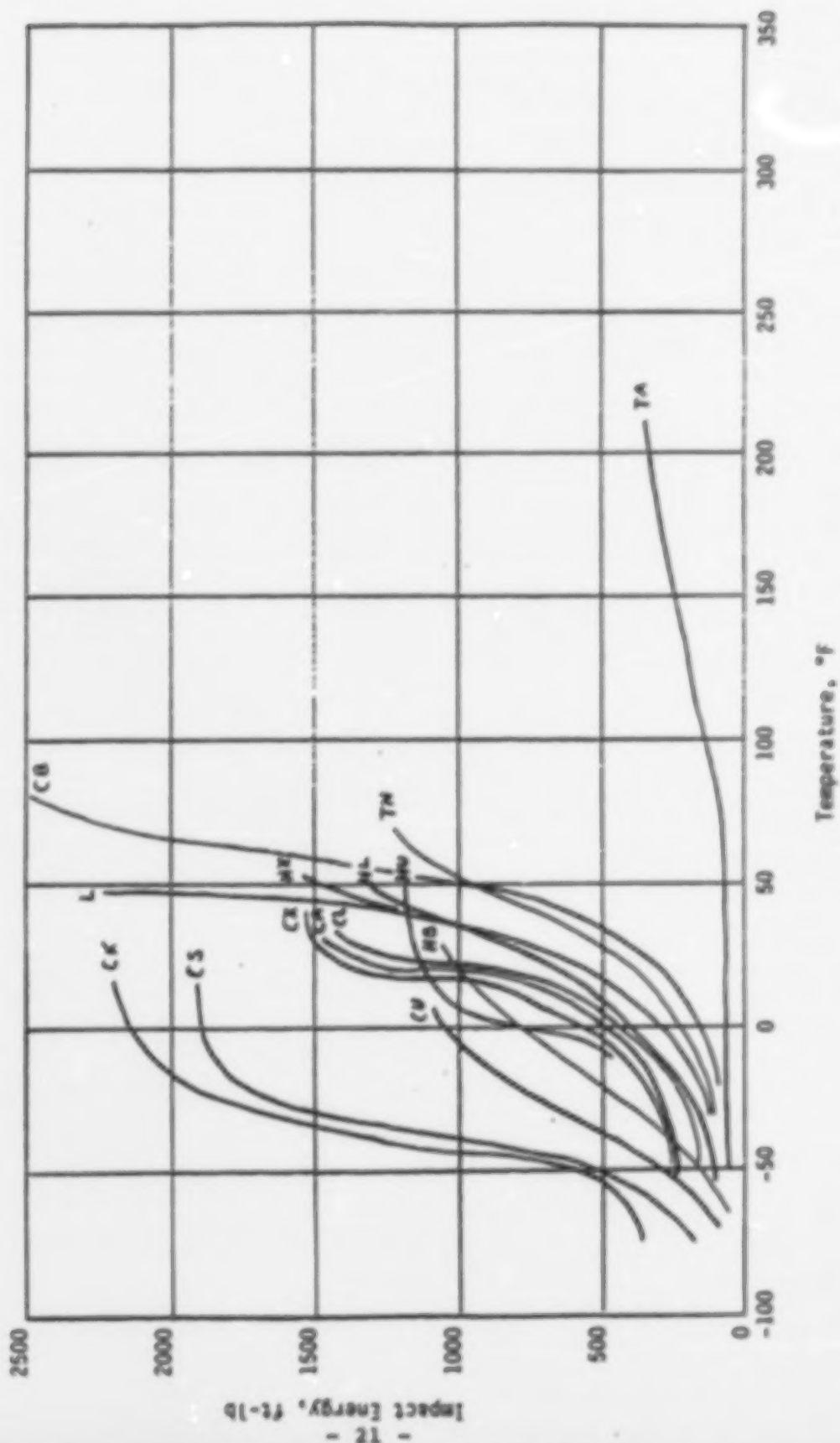


EXHIBIT 8

IMPACT PROPERTIES AND GRAIN SIZE OF BASE METAL

(Battelle, Appendix A)

Steel	NOT °F	CVN @ -50°F ft-lb ^{1/2}	Grain Size ^{4/}	
			Max.	Min.
TA	+30	32 (@ (+80°F)	9	8
TM	-40	40	10.5	9.5
L	-20	40	10	8.5
CA	-70	95	10.5	10
CX ^{2/}	-70	106	11	10
CB	-40	150	10.5	9.5
CK	-70	210	9.5	9.5
CL	-70	132	11	10
CS	-100	165	10	10
CU	-80	182	11	10
HB	-40	130	11	10.5
HL	-50	100	11	10
HX ^{2/}	-50	55	11	10
HS	Note 3	Note 3	10.5	9.5
HU	-50	77	9.5	9.5

^{1/} Values taken from curves for longitudinal specimen tests, Exhibit 6.

^{2/} CX and HX non-stress relieved. All others stress relieved at 1100°F for one hour.

^{3/} Data questionable. Will be retested.

^{4/} Per ASTM Spec. E112 utilizing the intercept procedure.

EXHIBIT 8

IMPACT PROPERTIES AND GRAIN SIZE OF BASE METAL

(Battelle, Appendix A)

Steel	NDT °F	CVN @ -50°F ft-lb ^{1/}	Grain Size ^{4/}	
			Max.	Min.
TA	+30	32 (@ (+80°F)	9	8
TN	-40	40	10.5	9.5
L	-20	40	10	8.5
CA	-70	95	10.5	10
CX ^{2/}	-70	106	11	10
CB	-40	150	10.5	9.5
CK	-70	210	9.5	9.5
CL	-70	132	11	10
CS	-100	165	10	10
CU	-80	182	11	10
HB	-40	130	11	10.5
HL	-50	100	11	10
HX ^{2/}	-50	55	11	10
HS	Note 3	Note 3	10.5	9.5
HU	-50	77	9.5	9.5

^{1/} Values taken from curves for longitudinal specimen tests, Exhibit 6.

^{2/} CX and HX non-stress relieved. All others stress relieved at 1100°F for one hour.

^{3/} Data questionable. Will be retested.

^{4/} Per ASTM Spec. E112 utilizing the intercept procedure.

RAILROAD TANK CAR SAFETY RESEARCH AND TEST PROJECT

AN RPI-AAR COOPERATIVE PROGRAM

PROJECT REVIEW COMMITTEE

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Railcar Services

J. J. Unger, President

ACF Industries, Inc.

September 5, 1990

PROJECT DIRECTOR

Earl A. Phillips

DEPUTY PROJECT DIRECTOR

C. P. Barkan

Dear Mr. :

The RPI-AAR Tank Car Safety Project (structured as shown on this letterhead) is a cooperative project sponsored by the major tank car companies and the Association of American Railroads.

As we discussed on the telephone, one of our major studies involves the evaluation of new type steels for use in tank car construction. Currently used steels are TC-128B (identical to ASTM A-612) and ASTM A-516-70.

We have developed a specification to cover the new steels, and sample plates have been produced by three steel companies. These steels have met our strength and toughness requirements, and we desire to obtain matching weld metal properties using the type of submerged arc welding practices normally used in our industry.

Four attachments to this letter define our welding requirements and the plates to be welded.

Attachment 1: Welding Requirements

Attachment 2: Plate specification

Attachment 3: Exhibits 1, 2, and 3 showing the properties of the plates on hand

Attachment 4: Chronology of Charpy Tests of Weld Metal of Butt Welded Joints

Reply to: Project Director - Tank Car Research

Association of American Railroads, Technical Center
3140 South Federal Street, Chicago, Illinois 60616
(312) 567-3807 Fax: (312) 567-5286

The fourth attachment summarizes our past weld metal tests. The results were satisfactory in the original program. That program involved 3/4" plates with multipass welds. As you can see, we encountered a problem in our current program.

We would like your company's recommendations for wire, flux and welding procedures to achieve our goal. After reviewing your recommendations, we may ask you to weld some 9/16" plate as a demonstration of the materials and procedures recommended. Following that, we may have tank car builders make similar test plates.

The companies involved in this steel study and their technical representatives are:

ACF Industries, Inc.	S. J. Coughlin (314) 344-4509
Trinity Industries, Inc.	S. W. Smith (214) 689-0830
Union Tank Car Co.	P. B. Heideman (219) 392-6291

I will be the focal point in this matter, and I will appreciate your sending your recommendations to me, with copies to the above people.

Sincerely,

E. A. Phillips
Project Director

EAP:md
Attachments

cc:	S. A. Coughlin	(ACF)
	P. B. Heideman	(UTC)
	S. W. Smith	(Trinity)

ATTACHMENT 1

REQUIREMENTS FOR SUBMERGED ARC WIRE AND FLUX FOR WELDING TANK CAR LONGITUDINAL AND CIRCUMFERENTIAL SEAMS.

BASE METALS TO BE WELDED

TYPE

AAR TC 135 GRADES A, B AND C.
Specification Given in Attachment 2
Properties of Plates on Hand Given in Attachment 3

THICKNESS

Plate Material from 7/16 TO 1" Thick

MECHANICAL PROPERTIES REQUIRED AFTER POST WELD HEAT TREATMENT 1150F FOR 1 HOUR

	Grade A	Grade B	Grade C
ACROSS-THE-WELD TENSILE			
Tensile Strength (ksi)	70 min	81 min	81 min
ALL-WELD-METAL TENSILE			
Tensile Strength (ksi)	70 min	81 min	81 min
Elongation 2" (%)	22 min	20 min	23 min
CHARPY (FT-LB -50 F) (Weld and HAZ)	25 min	25 min	25 min
PRODUCTION WELDS			
Hardness (Brinnell)	225 max	225 max	225 max

PREFERRED WELDING CONDITIONS

(Please comment on exceptions to the following)
PREHEAT: None above 32 F
OPERATING CHARACTERISTICS: Good operator appeal
WIRE DIAMETER: 1/8 through 3/16
PASSES: One pass each side at least up to 9/16" thick.
PROCESS: Can be used with DC/AC tandem submerged arc
BACK GOUGE: Not required

QUALITY REQUIREMENTS

PRESSURE VESSEL QUALITY WITH 100% RADIOGRAPHIC INSPECTION

Attachment 2

M135.00 SPECIFICATION FOR HIGH STRENGTH LOW ALLOY STEEL PLATES FOR TANK CARS AAR TC-135

DRAFT - JANUARY 21, 1990

M135.01 SCOPE

- (a) This specification covers steel plates intended primarily for use in fusion welded tank car tanks where improved weldability and low temperature notch toughness are desired.
- (b) Three grades are included. Grades A and B have 70 ksi and 81 ksi tensile strengths, respectively, and are produced by the control rolled process (CR) or thermo-mechanical control process (TMCP). Grade C has 81 ksi tensile strength and is for use in the normalized condition.
- (c) The CR and TMCP methods consist of rolling-reduction and cooling rate controls which result in mechanical properties in the finished plate that are equivalent to those attained using conventional rolling and heat treating processes which entail reheating after rolling to achieve desired properties (i.e., normalizing or quenching and tempering).
- (d) Due to the inherent characteristics of the CR and TMCP methods, the plates of Grades A and B formed at elevated temperatures may sustain losses in strength and toughness. The plates of Grades A, B and C may be formed and post-weld heat-treated at elevated temperatures, providing requirements of M135.06(a) are met.
- (e) The maximum nominal thickness of plates furnished under this specification may not exceed 1 in. (25 mm).
- (f) The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore each system must be used independently of the other. Combining values from the two systems may result in non-conformance with the specification.

M135.02 GENERAL REQUIREMENTS AND ORDERING INFORMATION

- (a) Material supplied to this material specification shall conform to ASTM Specification A20/A20M (Standard Specification for General Requirements for Steel Plates for Pressure Vessels). These requirements outline the testing and retesting methods and procedures, permissible variations in dimensions, quality and repair of defects, marking, loading, etc.
- (b) ASTM Specification A20/A20M also establishes the rules for ordering information which should be complied with when

purchasing material to this specification. When the material is to be subjected to elevated temperature forming or post-weld heat treatment, the order must indicate the temperatures and times-at-temperature that will be utilized in such operations. (See M135.06(a) and ASTM Specification A20/A20M, Supplementary Requirement S3.)

- (c) In addition to the basic requirements of this specification, certain supplementary requirements are available when additional control, testing, or examination is required to meet end use requirements. (See ASTM Specification A20/A20M.)
- (d) If the requirements of this specification are in conflict with the requirements of ASTM Specification A-20/A20M, the requirements of this specification shall prevail.

M135.03 MANUFACTURE

- (a) Steelmaking Practice—The steel shall be killed and shall be made to a fine austenitic grain size practice.
- (b) The plates for Grade A and B shall be produced by the CR or TMCP process.

M135.04 HEAT TREATMENT

- (a) Grades A and B plates shall be supplied in the as-rolled condition.
- (b) Grade C plates shall be normalized unless otherwise specified by the purchaser. When plates are ordered without normalizing, the purchaser shall be responsible for final normalizing heat treatment.

M135.05 CHEMICAL COMPOSITION

- (a) The chemical composition on heat and product analysis shall conform to the requirements listed in Table M135.01, except as otherwise provided in Supplementary Requirement S17 of ASTM Specification A20/A20M when that requirement is involved.

M135.06 MECHANICAL REQUIREMENTS

- (a) When the material is to be subjected to elevated temperature forming or post-weld heat treatment, the test coupons shall be subjected to heat treatment to simulate such fabrication operations. The maximum stress relief temperature for Grades A and B shall be 1200°F (650°C). (See M135.02(b) and ASTM Specification A20/A20M, Supplementary Requirement S3.)

(b) Tension Test Requirements

- (1) For Grades A and B, two tensile tests shall be made from each plate as-rolled. One test coupon shall be taken from a corner of the plate on each end.
- (2) For Grade C, one tensile test shall be made from each plate. Test coupons shall be normalized.
- (3) The plates as represented by the tension-test specimens shall conform to the requirements shown in Table M135.02.

(c) Notch Toughness Test Requirements

- (1) For Grades A and B, two longitudinal Charpy V-notch tests shall be made in accordance with ASTM Specification A20/A20M. One test coupon shall be taken from a corner of the plate on each end.
- (2) For Grade C, one longitudinal Charpy V-notch test shall be made in accordance with ASTM Specification A20/A20M. Test coupons shall be normalized.
- (3) The test results shall meet an average value (3 specimens) of 25 ft.lbs. at -50°F (34J at -46°C). The minimum for one value is 20 ft.lbs. (27J).

TABLE M135.01

CHEMICAL COMPOSITON

<u>ELEMENT</u>	<u>GRADE A</u>	<u>GRADE B</u>	<u>GRADE C</u>
	HEAT & PRODUCT ANALYSIS (3) <u>Percent</u>	HEAT & PRODUCT ANALYSIS (3) <u>Percent</u>	HEAT & PRODUCT ANALYSIS (3) <u>Percent</u>
Carbon	0.12 Max.	0.16 Max.	0.22 Max.
Manganese	1.00-1.75	1.00-1.75	1.00-1.60
Phosphorous	0.035 Max.	0.035 Max.	0.035 Max.
Sulphur	0.010 Max.	0.010 Max.	0.010 Max.
Silicon (1)	0.10-0.55	0.10-0.55	0.10-0.55
Columbium	0.06 Max.	0.06 Max.	0.05 Max.
Vanadium	0.11 Max.	0.11 Max.	0.12 Max.
Columbium plus Vanadium	0.16 Max.	0.16 Max.	0.16 Max.
Nitrogen	—	—	0.03 Max.
Carbon Equivalent (2)	0.42 Max.	0.47 Max.	0.52 Max.

- (1) If total aluminum content is 0.02% or greater, the requirement for a minimum silicon content may be deleted at the option of the producer.
- (2) As calculated using carbon equivalent formula:
- $$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15$$
- (3) The limits on unspecified elements per ASTM A20 Paragraph 7.1.1 apply.

DRAFT

Attachment 3

EXHIBIT 1

BASE PLATE CHEMICAL ANALYSES

(AAR Data)

Steel	Description	C	Mn	P	S	S:	Cb	V	Cb• V	N	Al Sol.	Al Acid	Cr	Mo	Cu	B	T:	Co	Ni	Carb Equiv 1/
TU2N	TC-128B-N	.23	1.22	.012	.010	.220	.006	.069	.069	.013	.030	.027	.22	.05	.24	.0005	.005	.005	.14	.52
AB2	Gr. A-AR	.07	1.36	.017	.006	.260	.034	.066	.100	.012	.064	.046	.06	.01	.20	.0005	.005	.005	.02	.34
BB2	Gr. B-AR	.13	1.36	.020	.006	.230	.031	.066	.099	.013	.067	.043	.06	.01	.20	.0005	.005	.005	.01	.40
BL2	Gr. B-AR	.10	1.31	.012	.006	.370	.036	.097	.132	.011	.024	.023	.19	.06	.23	.0011	.005	.005	.14	.41
CL2	Gr. C-N	.22	1.29	.013	.007	.240	.021	.071	.092	.016	.020	.019	.16	.04	.18	.0007	.005	.005	.13	.51
BU2	Gr. B-AR	Not analysed (same heat as CU2N)																		
CU2N	Gr. C-N	.17	1.36	.014	.010	.380	.034	.006	.039	.007	.046	.038	.14	.04	.26	.0005	.005	.005	.12	.46
CU2A	Gr. C-AR	Not analysed (same heat as CU2N)																		
AAR TC-136		Gr. A	.12	1.00-.036	.010	.10-.06	.11	.16	-	-	-	-	-	-	-	-	-	-	-	.42
		Gr. B	.16	1.76	.010	.06	.11	.16	-	-	-	-	-	-	-	-	-	-	-	.47
		Gr. C	.22	1.76	.010	.06	.12	.16	.03	-	-	-	-	-	-	-	-	-	-	.52
AAR TC-128		2/ Gr. B	.29	.92-.036	.040	.13-.06	.08	-	-	-	-	-	.25	.08	.35	-	-	-	.25	.66
		Gr. B	1.46	1.46	.46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1/ CE = C•Mn/6•(Cr•Mo•V)/5•(Cu•Ni)/16

2/ Product analysis

(EXHIBIT 1-7/10/90md)

DRAFT

EXHIBIT 2
BASE PLATE TENSILE PROPERTIES
(AAR Data - Transverse Specimens - all values
are average of two tests)

Note: Stress relieved (SR) tests were conducted using a 1.4" gage length and non-stress relieved tests were conducted using a 2.0" gage length

Steel	Description	Y.S. ksi	T.S. ksi	Elong %	RA %
TU2N	TC-128B-N SR	67.8	94.6	28.7	62.4
AB2	QR, A-AR SR	72.8	84.0	31.6	79.0
	NO SR	78.8	85.8	25.0	76.4
BB2	Gr. B-AR SR	79.6	84.0	27.0	60.5
	NO SR	80.8	85.8	21.4	54.4
BL2	Gr. B-AR SR	83.6	98.8	26.2	71.4
	NO SR	82.6	103.4	17.2	51.7
CL2	Gr. C-N SR	68.7	91.9	29.2	58.1
	NO SR	76.7	99.6	21.8	57.0
BU2	Gr. B-AR SR	77.4	101.1	21.8	46.2
	NO SR	67.9	98.7	19.8	46.0
CU2N	Gr. C-N SR	62.1	88.8	28.6	57.5
	NO SR	64.9	88.2	27.2	60.0

		Min	8"	2"
Gr. A	SR	60	70-90	18 22
Gr. B	SR	60	81-100	15 20
Gr. C	SR	60	81-100	18 23
Gr. B	SR	60	81-101	16 22

AAR
TC-136

AAR
TC-128

(EXHIBIT 2-7/10/90md)

ATTACHMENT 1

REQUIREMENTS FOR SUBMERGED ARC WIRE AND FLUX FOR WELDING
TANK CAR LONGITUDINAL AND CIRCUMFERENTIAL SEAMS.

BASE METALS TO BE WELDED

TYPE

AAR TC 135 GRADES A, B AND C.
Specification Given in Attachment 2
Properties of Plates on Hand Given in Attachment 3

THICKNESS

Plate Material from 7/16 TO 1" Thick

MECHANICAL PROPERTIES REQUIRED AFTER POST WELD HEAT TREATMENT
1150F FOR 1 HOUR

	Grade A	Grade B	Grade C
ACROSS-THE-WELD TENSILE			
Tensile Strength (ksi)	70 min	81 min	81 min
ALL-WELD-METAL TENSILE			
Tensile Strength (ksi)	70 min	81 min	81 min
Elongation 2" (%)	22 min	20 min	23 min
CHARPY (FT-LB -50 F) (Weld and HAZ)	25 min	^{34 J} 25 min	25 min
PRODUCTION WELDS			
Hardness (Brinnell)	^{234 HV} 225 max	225 max	225 max

PREFERRED WELDING CONDITIONS

(Please comment on exceptions to the following)
PREHEAT: None above 32 F
OPERATING CHARACTERISTICS: Good operator appeal
WIRE DIAMETER: 1/8 through 3/16
PASSES: One pass each side at least up to 9/16" thick.
PROCESS: Can be used with DC/AC tandem submerged arc
BACK GOUGE: Not required

QUALITY REQUIREMENTS

PRESSURE VESSEL QUALITY WITH 100% RADIOGRAPHIC INSPECTION

TABLE M135.02

TENSILE REQUIREMENTS

	<u>Grade A</u>	<u>Grade B</u>	<u>Grade C</u>
Tensile Strength psi (MPa)	70,000-90,000 (485-620)	81,000-100,000 (550-690)	81,000-100,000 (550-690)
Yield Strength Min psi (MPa)	50,000 (345)	60,000 (415)	60,000 (415)
Elongation in 8 In. (200mm) Minimum Percent (1)	18	15	18
Elongation in 2 In. (50mm) Minimum Percent (1)	22	20	23

(1) - See ASTM Specification A20/A20M

DRAFT

Attachment 3

EXHIBIT 3
BASE PLATE CHARPY V-NOTCH VALUES AT -50° F
(AAR Data)

Steel	Description	Longitudinal Spec.		Transverse Spec.	
		Energy absorbed ft-lbs ^{1/}	Shear fracture % ^{1/}	Energy absorbed ft-lbs ^{2/}	Shear fracture % ^{2/}
TU2H	TC-128B-N SR	26	29	26	6
	NO SR	-	-	-	-
AB2	Gr. A-AR SR	186	98	237	100
	NO SR	82	80	-	-
BB2	Gr. B-AR SR	73	76	64	80
	NO SR	126	95	-	-
BL2	Gr. B-AR SR	76	82	83	80
	NO SR	216	100	-	-
CL2	Gr. C-N SR	36	17	51	13
	NO SR	48	17	-	-
BU2	Gr. B-AR SR	67	77	49	67
	NO SR	23	8	-	-
CU2H	Gr. C-N SR	66	40	74	37
	NO SR	71	37	-	-

^{1/} Average of 12 values for SR specimens and
of 3 values for non-SR specimens

^{2/} Average of 3 values

Attachment 4

**Chronology of Charpy Tests of Weld Metal
of Butt Welded Joints**

(8/14/90 - EAP)

Test	Steel	Passes	Wire	Heat Input Joules/inch		Charpy V-notch -50°F ft-lbs
				High	Low	
Original program (App C, RA-83-7-53)	CB	3/side	LA-75		62,000	90, 90, 25
	CK	"	"		"	238, 132, 110
	TA	"	"		"	57, 12, 44
	TN	"	"		"	35, 18, 15
	L	"	"		"	16, 47, 26
	CA	"	"		"	36, 95, 80
	CE	"	"		"	48, 45, 41
	CU	"	"		"	13, 17, 38
	HB	"	"		"	9, 80, 87
	HL	"	"		"	30, 11, 14
	HS	"	"		"	21, 63, 78
	HU	"	"		"	34, 31, 11
Current program	All Steels	1/side	LS3	73,000	60,000	All poor (4 TO 17)
UTC 1 st retest	AB-2	4/side	"		53,000	poor, also @ -30°F
UTC 2 nd retest	BB-2	3/side 1/2	LA-75		58,000	36, 24, 11, 27, 19, 30
UTC 3 rd retest	BB-2	1/side	"		60,000	4; also 13, 6, 5, @ -30°F 2/

- Notes:
- All specimens PWHT @ 1200°F
 - All welding SAW (submerged arc)
 - Lincoln 880M flux used in all cases
 - LS3 wire OK for TC 125B-N, A-618-70-N (: 15 ft-lbs @ -50°F)

1/ 2 passes on 2nd side

2/ HAZ values OK (31 @ -50°F; 39, 163, 226, @ -30°F)

(CHRONOL-8/14/90md)

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J. J. Unger, President

ACF Industries, Inc.

PROJECT DIRECTOR

Earl A. Phillips

DEPUTY PROJECT DIRECTOR

C. P. Barkan

September 14, 1990

Subject: New Tank Car Steels

Dear Mr. :

This is a follow-up to my September 5, 1990 letter covering our RPI-AAR Tank Car Safety Project study of new tank car steels.

As further background, I attach the data sheets that covered the welding procedures used in our current program which led to the poor CVN's (4th line from bottom in Attachment 4 to my September 5, 1990 letter).

Sincerely,

E. A. Phillips
Project Director

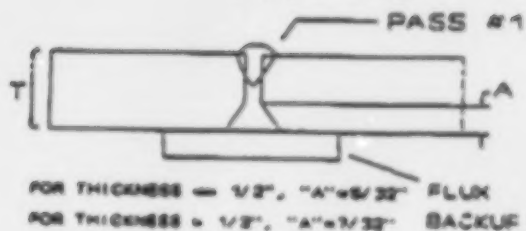
EAP:md
Attachments

cc: S. A. Coughlin (ACF)
P. B. Heideman (UTC)
S. W. Smith (Trinity)

Reply to: Project Director - Tank Car Research
Association of American Railroads, Technical Center
3140 South Federal Street, Chicago, Illinois 60616
(312) 567-3607 Fax: (312) 567-5266

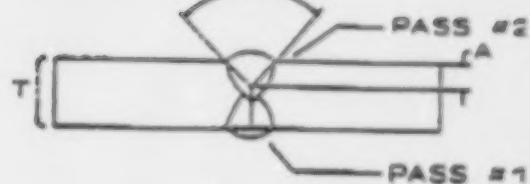
DETAIL 1A

9/16" - 1/16"



DETAIL 1B

90 degrees

LINCOLN LS3 ELECTRODE / 880H FLUX

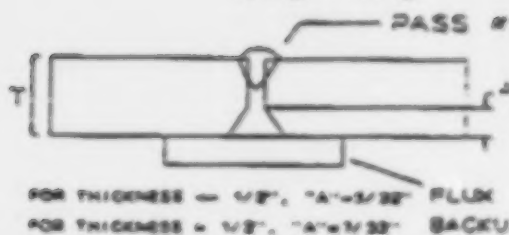
DETAIL	THICK- NESS	PASS NO.	POS.	DIA.	AMPS	VOLTS	TRAVEL SPEED	REMARKS
--------	----------------	-------------	------	------	------	-------	-----------------	---------

*Low Heat Input
Single Arc.*

1A	9/16"	1	1G	5/32"	650-700	31	20-22	DC
1B	9/16"	2	1G	5/32"	750	34	20-22	DC

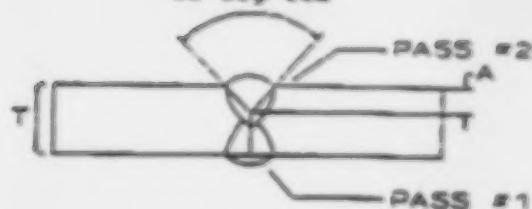
DETAIL 1A

T = 0 = 1/16"



DETAIL 1B

30 degrees

LINCOLN LS-3 ELECTRODE / 880M

DETAIL	THICK- NESS	PASS NO.	POS.	DIA.	AMPS	VOLTS	TRAVEL SPEED	REMARKS
--------	----------------	-------------	------	------	------	-------	-----------------	---------

*High Heat Input
Tandem Arc*

1A	9/16"	1	1G	5/32"	625-675	31	34-36	DC
1A	9/16"	1	1G	5/32"	600	37	34-36	AC
1B	9/16"	2	1G	5/32"	950	34	36	DC
1B	9/16"	2	1G	5/32"	600	37	36	AC

G.S.

RAILROAD TANK CAR SAFETY RESEARCH AND TEST PROJECT

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PROJECT DIRECTOR
Earl A. Phillips

DEPUTY PROJECT DIRECTOR
C. P. Barkan

October 5, 1990

Mr. George P. Binns
The Atchison, Topeka & Santa Fe
1001 N.W. Atchison St.
Topeka, KS 66616

Subject: New Tank Car Steels

Dear George:

This is a status report for your use at the forthcoming AAR Tank Car Committee meeting.

The basic problem with the steels we have tested is the low Charpy values in the weld metal of the butt welded joints. At the July meeting of the Steel T/F we were optimistic that Union Tank would be successful in their retest efforts, but that did not turn out to be the case. At that point we decided to enlist help from the weld wire suppliers. We wrote to the three majors on September 5 and September 14, 1990. A copy of these letters and their attachments is enclosed for your information.

We received an interesting response from Hobart which basically attributes the problem to the presence in the base metal of Cb, V and to a lesser extent, Al and N. Lincoln is welding some plates to study the problem, and we have not yet heard from L-Tec.

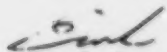
Hopefully, we will have enough information of interest to review this problem, as well as the entire program, at the January, 1991 meeting.

Reply to: Project Director - Tank Car Research
Association of American Railroads, Technical Center
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Mr. George P. Binns
October 5, 1990
Page 2

I will keep you advised of any significant developments.

Sincerely,


Earl A. Phillips
Project Director

EAP:md
Att.

cc: w/enc.

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Association of American Railroads
Manual of Standards and Recommended Practices
Specifications for Tank Cars

Stainless steel

ASTM A240 Types 304, 304L, 316, 316L

Aluminum

ASTM B221 Extruded Shapes, Alloy 6061-T4, -T6

**M128.00 SPECIFICATION FOR HIGH STRENGTH CARBON MANGANESE
STEEL PLATES FOR TANK CARS—AAR TC128**

M128.01 SCOPE

(a) This specification covers one grade of high strength carbon manganese steel plate for use in fusion welded tank car tanks. The maximum thickness must be 1 inch (25.4 millimeters). Moderately high manganese content, together with small amounts of other elements, provide for high strength with limited carbon content. The steel must be made to fine grain practice. Welding technique is of fundamental importance, and it is presupposed that welding procedure will be in accord with good practice.

(b) The material must be furnished in the as-rolled or normalized condition. When specified for low temperature service, the material must be furnished normalized to meet the Charpy V-notch energy absorption requirements of 15 ft-lb (20.3 joules) minimum average for 3 specimens, and 10 ft-lb (13.6 joules) minimum for one specimen, at minus 50F (minus 45.6°C) in the longitudinal direction of rolling, in accord with ASTM A370.

M128.02 GENERAL CONDITION FOR DELIVERY

Material furnished under this specification must conform to the applicable requirements of ASTM A20, titled "General Requirements for Steel Plates for Pressure Vessels", except, when specified for low temperature service, refer to M128.01(b) for the energy absorption requirement, only.

M128.03 PROCESS

The steel must be made by the open hearth, electric furnace or basic oxygen process.

M128.04 CHEMICAL COMPOSITION

The steel must conform to the chemical composition requirements prescribed in Table M128.04.

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**TABLE M128.04
CHEMICAL REQUIREMENTS**

Element		Grade B	
		Ladle Analysis, Percent	Product Analysis, Percent
Carbon	Max.	0.25	0.29
Manganese			
For plates $\frac{3}{4}$ " (19.0 mm) and under in thickness		1.00-1.35	0.92-1.46
For plates over $\frac{3}{4}$ " to 1" (over 19.0 to 25.4 mm) in thickness		1.00-1.50	0.92-1.62
Phosphorus	Max.	0.035	0.035
Sulfur	Max.	0.040	0.040
Silicon			
For plates $\frac{3}{4}$ " (19.0 mm) and under in thickness		0.15-0.40	0.15-0.40
For plates over $\frac{3}{4}$ " to 1" (over 19.0 to 25.4 mm) in thickness		0.15-0.50	0.13-0.55
Vanadium a/	Max.	0.08	0.08
Copper a/	Max.	0.35	0.35
Nickel a/	Max.	0.25	0.25
Chromium a/	Max.	0.25	0.25
Molybdenum a/	Max.	0.08	0.08

a/ These elements will be reported when requested by the purchaser.

M128.06 TENSILE PROPERTIES

The material as represented by the test specimens must conform to the tensile properties prescribed in Table M128.05.

**TABLE M128.05
TENSILE REQUIREMENTS**

Property		Grade B
Tensile strength, psi (MPa)		81,000 to 101,000 (560 to 695)
Yield strength, psi (MPa)	Min.	50,000 (345)
Elongation in 8 in. (200 mm) percent	Min.	16.0 a/
Elongation in 2 in. (50 mm) percent	Min.	22.0

a/ For material under $\frac{5}{16}$ inch (7.94 mm) thick, a reduction from the specified percent elongation of 1.25 percent must be made for each decrease of $\frac{1}{32}$ inch (0.794 mm) of thickness below $\frac{5}{16}$ inch (7.94 mm). For material over $\frac{3}{4}$ inch (19.0 mm) thick, a reduction from the specified percent elongation of 0.5 percent must be made for each increase of $\frac{1}{8}$ inch (3.18 mm) of the thickness above $\frac{3}{4}$ inch (19.0 mm). This reduction must not exceed 3 percent.

M128.06 Open.

M128.07 TEST SPECIMENS

Test specimens furnished by the steel manufacturer must be prepared from the material in the condition specified for the plate use, such as normalized, as-rolled or postweld heat treated.

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Specifications for Tank Cars

M128.08 NUMBER OF TESTS

One tension test must be made from each plate as rolled.

Note: The term "plate as rolled" used here refers to the unit plate rolled from a slab, or directly from an ingot, in its relation to the location and number of specimens, not to its condition.

M128.09 INSPECTION

(a) The inspector representing the purchaser shall have free entry, while the work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material. The manufacturer shall afford the inspector, free of charge, all reasonable facilities and necessary assistance to satisfy him that the material is being furnished in accord with these specifications. Tests and inspection must be made at the place of manufacture, prior to shipment, unless otherwise specified.

(b) The purchaser may make tests to cover the acceptance or rejection of the material in his own laboratory or elsewhere. Such tests must be made at the expense of the purchaser.

M128.10 REJECTION

(a) Material represented by samples which fail to conform to the requirements of these specifications will be rejected.

(b) Material which shows injurious defects, subsequent to its original inspection and acceptance at the manufacturer's works, or elsewhere, will be rejected, and the manufacturer must be notified.

M128.11 REHEARING

Samples, tested in accord with these specifications, which represent rejected material must be held for a period of fourteen days from date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

**M133.00 SPECIFICATION FOR HIGH STRENGTH NINE PERCENT NICKEL
ALLOY STEEL PLATES, DOUBLE NORMALIZED AND TEMPERED—AAR TC133**

M133.01 SCOPE

(a) This specification covers high strength nine percent nickel alloy steel plates, double normalized and tempered, for use in fusion welded tank car tanks.

(b) Material furnished under this specification must conform to the requirements of ASTM A353, with modifications to chemical composition and impact requirements as follows:



Standard Specification for Pressure Vessel Plates, Carbon Steel, High Strength, for Moderate and Lower Temperature Service¹

This standard is issued under the fixed designation A 612/A 612M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification² covers killed carbon-manganese-silicon steel plates intended for welded pressure vessels in service at moderate and lower temperatures.

1.2 The maximum thickness of plates supplied under this specification is 1 in. [25 mm].

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 ASTM Standards:

- A 20/A 20M Specification for General Requirements for Steel Plates for Pressure Vessels³
- A 435/A 435M Specification for Straight-Beam Ultrasonic Examination of Steel Plates³
- A 577/A 577M Specification for Ultrasonic Angle-Beam Examination of Steel Plates³
- A 578/A 578M Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications³

3. General Requirements and Ordering Information

3.1 Material supplied to this material specification shall conform to Specification A 20/A 20M. These requirements outline the testing and retesting methods and procedures.

¹ This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.11 on Steel for Boilers and Pressure Vessels.

Current edition approved March 27, 1987. Published May 1987. Originally published as A 612 - 70. Last previous edition A 612/A 612M - 86.

² For ASME Boiler and Pressure Vessel Code applications see related Specification SA-612 in Section II of that Code.

³ Annual Book of ASTM Standards, Vol 01.04.

permissible variations in dimensions and weight, quality of repair of defects, marking, loading, etc.

3.2 Specification A 20/A 20M also establishes the requirements for the ordering information that should be complied with when purchasing material to this specification.

3.3 In addition to the basic requirements of this specification, certain supplementary requirements are available. Additional control, testing, or examination is required to meet end use requirements. These include:

- 3.3.1 Vacuum treatment,
- 3.3.2 Additional or special tension testing,
- 3.3.3 Impact testing, and
- 3.3.4 Nondestructive examination.

3.4 The purchaser is referred to the listed supplementary requirements in this specification and to the detailed requirements in Specification A 20/A 20M.

3.5 If the requirements of this specification are in conflict with the requirements of Specification A 20/A 20M, the requirements of this specification shall prevail.

4. Manufacture

4.1 *Steelmaking Practice*—The steel shall be killed and shall conform to the fine austenitic grain size requirements of Specification A 20/A 20M.

5. Heat Treatment

5.1 Plates are normally supplied in the as-rolled condition. Plates may be ordered normalized or stress relieved.

6. Chemical Requirements

6.1 The steel shall conform to the requirements for chemical composition shown in Table 1 unless otherwise modified in accordance with Supplementary Requirements S17, Vacuum Carbon-Deoxidized Steel, in Specification A 20/A 20M.

7. Mechanical Requirements

7.1 *Tension Test Requirements*—The material supplied by the tension test specimens shall conform to the requirements shown in Table 2.

TABLE 1 Chemical Requirements

Elements	Composition, %	
	Thickness	
	0.750 in. [20 mm] and Under	Over 0.750 to 1 in. [20 to 25 mm], incl
Carbon, max:		
Heat analysis	0.25	0.25
Product analysis	0.29	0.29
Manganese		
Heat analysis	1.00-1.35	1.00-1.50
Product analysis	0.92-1.46	0.92-1.62
Phosphorus, max ^A	0.035	0.035
Sulfur, max ^A	0.040	0.040
Silicon		
Heat analysis	0.15-0.40	0.15-0.50
Product analysis	0.13-0.45	0.13-0.55
Copper, max ^B		
Heat analysis	0.35	0.35
Product analysis	0.38	0.38
Nickel, max ^B		
Heat analysis	0.25	0.25
Product analysis	0.28	0.28
Chromium, max ^B		
Heat analysis	0.25	0.25
Product analysis	0.29	0.29
Molybdenum, max ^B		
Heat analysis	0.08	0.08
Product analysis	0.09	0.09
Vanadium, max ^B		
Heat analysis	0.08	0.08
Product analysis	0.09	0.09

^A Applies to both heat and product analyses.

^B When analysis shows that the amount of an element is 0.02 % or lower, the value may be reported as ≤ 0.02 %.

TABLE 2 Tensile Requirements

	Thickness	
	0.5 in. [12.5 mm] and Under	Over 0.5 in. to 1 in. [Over 12.5 to 25 mm]
Tensile strength, ksi [MPa]	83-105 [570-725]	81-101 [560-695]
Yield strength, min. ^A ksi [MPa]	50 [345]	50 [345]
Elongation in 8 in. [200 mm], min. % ^B	18	16
Elongation in 2 in. [50 mm], min. % ^B	22	22

^A Determined by either the 0.2 % offset method or the 0.5 % extension-under-load method.

^B See Specification A 20/A 20M.

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall not apply unless specified in the order.

A list of standardized supplementary requirements for use at the option of the purchaser are included in Specification A 20/A 20M. Several of those considered suitable for use with this specification are listed by title. Other tests may be performed by agreement between the supplier and the purchaser.

- S1. Vacuum Treatment,
- S2. Product Analysis,
- S3. Simulated Post-Weld Heat Treatment of Test Coupons,
- S4.1 Additional Tension Test,
- S5. Charpy V-Notch Impact Test,
- S6. Drop Weight Test,
- S7. High Temperature Tension Test,

- S8. Ultrasonic Examination in accordance with Specification A 435/A 435M,
- S9. Magnetic Particle Examination,
- S11. Ultrasonic Examination in accordance with Specification A 577/A 577M,
- S12. Ultrasonic Examination in accordance with Specification A 578/A 578M,
- S14. Bend Test, and
- S17. Vacuum Carbon-Deoxidized Steel.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.



Designation: A 808/A 808M - 88

Standard Specification for High-Strength, Low-Alloy Carbon, Manganese, Columbium, Vanadium Steel of Structural Quality with Improved Notch Toughness¹

This standard is issued under the fixed designation A 808/A 808M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last approval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or approval.

1. Scope

1.1 This specification covers hot-rolled, high-strength, low-alloy steel plate with improved notch toughness in the as-rolled condition.

1.2 The maximum thickness available is 2½ in. [65 mm].

1.3 When the steel is to be welded, it is presupposed that a welding procedure suitable for the grade of steel and intended use or service will be utilized.

1.4 The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents. Therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.

2. Referenced Documents

2.1 ASTM Standards:

A 6/A 6M Specification for General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use²

A 673/A 673M Specification for Sampling Procedure for Impact Testing of Structural Steel²

3. General Requirements for Delivery

3.1 Material furnished to this specification shall conform to the applicable requirements of the current edition of Specification A 6/A 6M.

4. Process

4.1 The steel shall be made by one or more of the following processes: open-hearth, basic oxygen, or electric furnace.

4.2 The steel shall be made to a fine grain practice.

¹ This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.02 on Structural Steel for Bridges, Buildings, Rolling Stock, and Ships.

Current edition approved March 16, 1988. Published May 1988. Originally published as A 808 - 82. Last previous edition A 808/A 808M - 87.

² Annual Book of ASTM Standards, Vol 01.04.

TABLE 1 Chemical Requirements

Elements	Composition, %
Carbon	0.12 max
Manganese	1.85 max
Phosphorus	0.04 max
Sulfur ^a	0.06 max
Silicon	0.15 to 0.50
Columbium ^b	0.02 to 0.10
Vanadium ^b	0.10 max
Columbium plus Vanadium ^b	0.15 max

^a May also be produced restricted sulfur 0.010 maximum.

^b Either columbium, or vanadium, or columbium plus vanadium may be used to the limits shown in this table.

5. Chemical Requirements

5.1 The heat analysis shall conform to the requirements shown in Table 1.

5.2 The steel shall conform on product analysis to the requirements prescribed in Table 1 subject to the product analysis tolerances in Specification A 6/A 6M.

6. Mechanical Requirements

6.1 Tensile Properties:

6.1.1 The material as represented by the test specimen shall conform to the tensile properties given in Table 2.

6.2 Charpy V-Notch Impact Properties:

6.2.1 The Charpy V-Notch impact tests shall be conducted in accordance with Specification A 673/A 673M.

TABLE 2 Tensile Requirements^a

Thickness, in. [mm]	Minimum Yield Point, ksi [MPa]	Tensile Strength, min. ksi [MPa]	Elongation, % min	
			2 in. [50 mm]	8 in. [200 mm]
Up to 1½ [40], incl	80 [345]	88 [400] ^b	22	18 ^c
Over 1½ to 2 [40 to 50], incl	46 [315]	88 [400]	22	18
Over 2 to 2½ [50 to 65], incl	42 [290]	80 [415]	22	18

^a For plates under than 24 in. [600 mm], the tensile test specimen is taken in the transverse direction. See Orientation under the Tension Tests section of Specification A 6/A 6M.

^b Prior to A 808/A 808M - 88, the minimum tensile strength was 70 ksi [480 MPa].

^c For nominal thicknesses under ¼ in. [8 mm], a deduction from the specified percentage of elongation in 8 in. [200 mm] shall be made for decreases of nominal thickness below ¼ in. [8 mm]. See elongation requirement adjustment under the Tension Tests section of Specification A 6/A 6M for deduction values.

A 808/A 808M

6.2.2 The frequency of testing (see Specification A 673/A 673M), the impact test temperature, and the absorbed energy requirement shall be as agreed upon between purchaser and manufacturer. The highest guaranteed absorbed energy and the lowest temperature normally available are shown in Table 3.

TABLE 3 Charpy V-Notch Impact Test Values

Type	Temperature, °F [°C]	Average Absorbed Energy, ft-lbf [J]
Recurrent sulfur	-20 [-30]	55 [75]
	-60 [-48]	45 [61]
Regular sulfur	-20 [-30]	40 [54]
	-60 [-48]	30 [41]

SUPPLEMENTARY REQUIREMENTS

The supplementary requirement listed in this section shall not apply unless specified in the order. Requirements other than the one listed in this section may be specified subject to agreement between the supplier and the purchaser.

S14. Bend Test

Specification A 6/A 6M, Supplementary Requirement S14.

S14.1 The bend test shall be made in accordance with

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temperature, and acceptance criteria. For drop-weight test (give testing temperature),

4.1.7 Either plates from coil or discrete cut lengths of flat product may be supplied unless one is specifically excluded on the order. (See Appendix XI.)

4.1.8 If the processor (see 5.5.2) intends to qualify plates cut from a coiled product as pressure vessel plates, the order to the manufacturer (see 5.5.1) should state the intended ASTM specification designation, grade, and type (as applicable).

4.1.9 Supplementary requirements, if any (test specimen heat treatment, special impact test requirements, etc.), and

4.1.10 Additional requirements, if any.

5. Manufacture

5.1 The steel shall be produced by one of the following primary steelmaking processes: open hearth, basic oxygen, electric furnace. The steel may be further refined by secondary processes, including but not restricted to: vacuum-secondary processes, including but not restricted to: vacuum-arc remelt (VAR), electroslag remelt (ESR), and ladle treatment.

5.2 The steel may be cast in ingots or may be strand cast.

5.2.1 Strand Cast Slabs:

5.2.1.1 When heats of the same nominal chemical composition are consecutively strand cast at one time, the heat number assigned to the cast product (slab) may remain unchanged until all of the steel in the slab is from the following heat.

5.2.1.2 When two consecutively strand cast heats have different nominal chemical composition ranges, the manufacturer shall remove the transition material by any established procedure that positively separates the grades.

5.3 The ratio of reduction of thickness from a strand-cast slab to plate shall be a minimum of 3 to 1.

5.4 Plates are produced in either discrete cut lengths of flat product or from coils.

5.4.1 Plates produced from coil means plates that have been leveled or flattened and cut to length from a coiled product and that are furnished without heat treatment. For the purposes of this paragraph, stress relieving is not considered to be a heat treatment.

5.4.2 Plates that are annealed, normalized, normalized-and-tempered, or quenched-and-tempered after decoiling shall be considered to be discrete cut lengths of flat products.

5.5 When plates are produced from coils:

5.5.1 The manufacturer directly controls one or more of the operations (that is, melting, rolling, coiling, etc.) that affect the chemical composition or the mechanical properties, or both, of the material.

5.5.2 The processor decoils, cuts to length, and marks; performs and certifies tests, examination repairs, inspection, or operations not intended to affect the properties of the material. The processor may subsequently heat treat the plates (see Section 6). Specific sections of this specification for which the processor is responsible are 9, 10, 11, 12, 13, 14, 15, 16, 19, and 20.

6. Heat Treatment

6.1 When material is required to be heat treated, the heat treatment may be performed either by the manufacturer or

processor or by the fabricator unless otherwise specified in the material specification.

6.2 When the heat treatment required by the material specification is to be performed by the purchaser or the purchaser's agent, and the material is to be supplied by the material producer in a condition other than that required by the material specification, the order shall so state.

6.2.1 When plates are ordered without the heat treatment required by the material specification, heat treatment of the plates to conform to the requirements of the material specification shall be the responsibility of the purchaser.

6.3 When heat treatment is to be performed, the material shall be heat treated as specified in the material specification. The purchaser may specify the heat treatment to be used provided it is not in conflict with the requirements of the material specification.

6.4 When normalizing is to be performed by the fabricator, it may be accomplished by heating uniformly for hot forming. The temperature to which the plates are heated for hot forming shall not significantly exceed the normalizing temperature.

6.5 When no heat treatment is required, the manufacturer or processor may opt to heat treat the plates by normalizing, stress relieving, or normalizing and then stress relieving to meet the material specification.

6.6 If approved by the purchaser, cooling rates faster than those obtained by cooling in air are permissible for improvement of the toughness, provided the plates are subsequently tempered in the temperature range from 1100 to 1300°F (595 to 705°C).

7. Chemical Analyses

7.1 Heat Analysis of each heat shall be made by the manufacturer to determine the percentage of elements specified in the individual material specification. This analysis shall be made from a test specimen preferably taken during the pouring of the heat. The chemical composition thus determined shall be reported to the purchaser, or the purchaser's representative, and shall conform to the heat analysis requirements of the applicable specification.

7.1.1 Unspecified elements may be present. Unless otherwise specified in the material specification, limits on elements shall be as stated in Table 1.

7.1.1.1 Each of the elements listed in Table 1 shall be included in the report of the heat analysis. When the amount of an element present is less than 0.02 %, the analysis may be reported as "<0.02 %."

7.2 Product Analysis representing each plate as-rolled may be made by the purchaser from a broken tension test specimen or from a sample taken from the same relative location as that from which the tension test specimen was obtained. The chemical composition thus determined, as to elements required or restricted, shall conform to the product analysis requirements specified in the applicable specification.

7.3 Referee Analysis—For referee purposes, Methods, Fractions, and Definitions A 751 shall be used.

8. Metallurgical Structure

8.1 When a coarse austenitic grain size is specified, the steel shall have a carburized austenitic grain size number of 1

TABLE 1 Limits on Unspecified Elements (see 7.1.1)

Copper, max % ^a	Heat analysis	0.40
	Product analysis	0.43
Nickel, max % ^a	Heat analysis	0.40
	Product analysis	0.43
Chromium, max % ^{a,b}	Heat analysis	0.30
	Product analysis	0.34
Molybdenum, max % ^{a,b}	Heat analysis	0.12
	Product analysis	0.13
Vanadium, max % ^c	Heat analysis	0.03
	Product analysis	0.04
Columbium, max % ^c	Heat analysis	0.02
	Product analysis	0.03

^a The sum of copper, nickel, chromium, and molybdenum shall not exceed 1.00 % on heat analysis. When one or more of these elements are specified, the sum does not apply; in which case, only the individual limits on the remaining unspecified elements will apply.

^b The sum of chromium and molybdenum shall not exceed 0.32 % on heat analysis. When one or more of these elements are specified, the sum does not apply; in which case, only the individual limits on the remaining unspecified elements will apply.

^c By agreement, the heat analysis limits for vanadium or columbium, or both, may be increased up to 0.10 % and 0.05 %, respectively.

to 5 as determined by the McQuaid-Ehn test. Determination shall be in accordance with Methods E 112, Plate IV, by carburizing for 8 h at 1700°F (925°C). Conformance to this grain size of 70 % of the grains in the area examined shall constitute the basis of acceptance. One test per heat shall be made.

8.2 Fine Austenitic Grain Size

8.2.1 When a fine austenitic grain size is specified, aluminum shall be used as the grain refining element unless the order provides otherwise as specified in 8.2.4.

8.2.2 When a fine austenitic grain size is specified, except as otherwise provided in 8.2.2.1, the steel shall have a carburized austenitic grain size number of 5 or higher (finer) as determined by the McQuaid-Ehn test in accordance with Methods E 112, Plate IV. One test per heat shall be made.

8.2.2.1 When aluminum is used as the grain refining element, the fine austenitic grain size requirement shall be deemed to be fulfilled if, on heat analysis, the aluminum content is not less than 0.020 % total aluminum or, alternatively, 0.015 % acid soluble aluminum.

8.2.3 When specified on the order, one McQuaid-Ehn test (see 8.1) per heat shall be made and the austenitic grain size of the steel, as represented by the test, shall be Number 5 or finer.

8.2.4 By agreement between the purchaser and the supplier, elements other than aluminum may be used for grain refining. In such instances, the heat analysis limits for the element, or elements, permitted shall be specified on the order. In addition, the McQuaid-Ehn test of 8.2.3 shall be required.

9. Quality

9.1 General—Plates furnished under this specification shall be free of injurious defects and shall have a workmanlike finish.

9.2 Surface Imperfections

9.2.1 All injurious surface imperfections shall be removed

by the manufacturer of discrete cut length plate provided from coils, the processor shall remove imperfections, rather than the manufacturer.

9.2.1.1 Shallow imperfections shall be ground metal; the ground area shall be well faired and of the ground plate shall not be reduced below thickness permitted.

9.2.1.2 All surface imperfections, the removal will reduce the plate thickness below this minimum cause for rejection of the plate; however, by agreement with the purchaser, the metal so removed may be weld metal as provided in 9.4.

9.3 Edge Imperfections

9.3.1 Laminar-type discontinuities 1 in. [25.4 mm] in length visible to the unaided eye on the edge prepared for shipment by the manufacturer or processor are acceptable and do not require exploration.

9.3.2 All larger discontinuities shall be explored to determine their depth and extent. Discontinuities shall be considered continuous when located in the same plane of the plate thickness and separated by a distance less than the length of the smaller of two adjacent discontinuities.

9.3.3 Indications visible to the unaided eye on the edges of a plate as prepared for shipment by the manufacturer or processor shall not exceed the limits given in columns 1 and 2 of Table A1.14 [A2.14].

9.3.4 Larger indications shall be removed by the manufacturer or processor by grinding provided the removal does not exceed the limits given in columns 3 and 4 of Table A1.14 [A2.14].

9.3.5 Indications of greater magnitude shall be cause for rejection of a plate; however, by agreement with the purchaser, the defects may be removed and replaced with weld metal as provided in 9.4.

9.3.6 Indications on the edges of a plate as prepared for fabrication shall be cause for rejection of the plate at the discretion of the purchaser when the magnitude of the defects exceeds the limits given in columns 5 and 6 of Table A1.14 [A2.14]. Defects may be removed and replaced with weld metal as provided in 9.4.

9.4 Repair by Welding

9.4.1 Repair welding shall be permitted only with the approval of the purchaser.

9.4.2 Preparation for repair welding shall include grinding to assure complete removal of the defect.

9.4.3 Repairs shall be made utilizing weld metal qualified in accordance with Section IX of the ASME Code and repair welding shall be done by welders meeting the qualification requirements of Section IX.

9.4.4 The weld metal shall have the A-number corresponding to the equivalent ASME P-number for the plate material except that A-1 or A-2 analysis may be employed for P-1 materials. Other materials may be employed that are compatible with the base metal being repaired, when so approved by the purchaser. Weld metals must be qualified in accordance with the requirements of Section IX of the ASME Code.

9.4.5 If Charpy impact tests are required for the material, the welding procedure qualification shall include Charpy impact tests of the weld, heat